New Scientist

13/20 December 2025

2025 IN REVIEW

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This week's issue

Christmas & New Year special

New Scientist
CHRISTMAS & NEW YEAR SPECIAL
2025 IN REVIEW

Vol 268 No 3573/3574
Cover image: Brett Ryder

Dear reader,
Welcome to our bumper holiday issue, filled to the brim with seasonal delights to keep you entertained over the festive period. This year we discover tips for living longer from the world's oldest animal, investigate whether we live in a simulation and enjoy the tale of an audacious attempt to recreate the aurora. We also have our review of the year, tricky riddles and a quiz to give the brain a workout, plus our list of the greatest books, films and TV to catch up on, and so much more. Wishing you a very happy holiday!

Eleanor Parsons
New Scientist magazine editor

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The brilliant Bel Canto

The (GPHG Award-winning) FS01 chiming module in all Bel Cantos orchestrates a crystal-clear 'D' note. Every hour on the hour. Now, with a '**Lumière**' addition to the cast, you can opt for an accompanying visual extravaganza, too. A production that may have admirers talking to your wrist during the day. And a light show making it difficult to look away from at night. Bravo!

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PROSTATE CANCER UK

Disappointed but determined: We will not stop until we achieve screening for all men

By Laura Kerby, CEO of Prostate Cancer UK

Despite deep disappointment at a recent decision to not recommend screening for the vast majority of men at risk, we, says Prostate Cancer UK's CEO Laura Kerby, remain determined to unlock a better future. Our £42 million research programme holds the key.

Dads. Brothers. Partners. Friends. We all know someone whose life has been changed forever by the most common cancer in men. Too many of us have lost that person. This disease kills 12,000 men every year.

That is why the decision of the UK National Screening Committee (NSC) to not recommend screening for the vast majority of men at risk of prostate cancer feels so personal. So disappointing. So hard to accept.

But it is vitally important that we understand and learn from it. Because it pinpoints exactly what we must do to achieve screening and build a better future for men. The modelling the NSC commissioned to make this difficult decision indicates where there are gaps in the evidence. In doing so, it highlights where our cutting-edge research can close these gaps and change the outcome.

As the largest public funder of prostate cancer research in the UK, Prostate Cancer UK has invested over £120 million into research that has made diagnosis and treatment of prostate cancer safer and more accurate than ever before. We've also helped tens of thousands of men campaign for change, share their stories to influence policymakers, and advocate to improve men's health and fight health inequalities across the UK. One example: to help build strong foundations for a future screening programme, earlier this year we successfully campaigned for NICE to update outdated Active Surveillance guidelines. A large concern around screening is how it could lead to increases in men having treatment they may not need, but by updating the guidelines and helping GPs to better inform their patients, we can potentially reduce this overtreatment for 5,000 men every year.

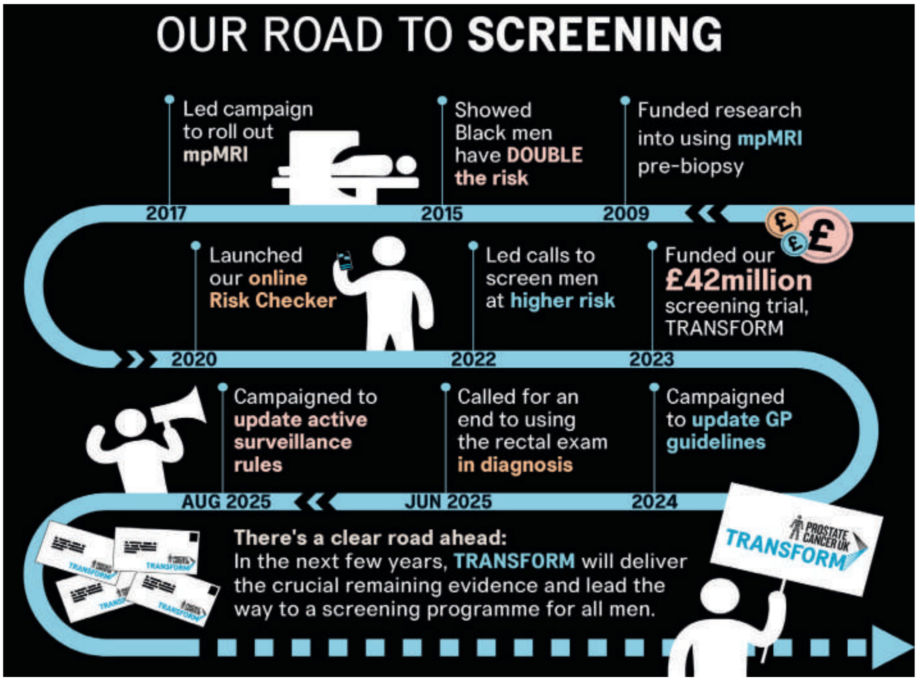
Around
1,050,000
new cases of
prostate cancer
by 2040.

As we saw changes to the science, we pushed for changes to the system. We led the submission of the evidence to the screening committee's latest review, making the case for targeted screening for men at highest risk including Black men, who are twice as likely to be diagnosed with and die from prostate cancer compared to white men. We believe screening for these men would save lives and help bring an end to shocking inequalities in prostate cancer diagnosis.

We're reviewing the committee's report in detail, to fully understand the rationale for its decision. But we're confident the evidence is there to take urgent, lifesaving action for Black men, and so we are challenging the Government to set out a clear plan for tackling late diagnosis and the inequities that are leaving Black men's lives to chance.

In the meantime, we're investing £4.6 million over the next five years to end the inequalities for Black men facing prostate cancer – including a £3.6 million Black Health Equity strategy and a £1 million funding call for 'real world evidence' projects, which will provide vital data to help build an even stronger case for screening Black men.

1 in 8 men in the UK will get prostate cancer



OUR ROAD TO **SCREENING**

2009 – Funded research into using **mpMRI** pre-biopsy

2015 – Showed Black men have **DOUBLE the risk**

2017 – Led campaign to roll out **mpMRI**

2020 – Launched our **online Risk Checker**

2022 – Led calls to screen men at **higher risk**

2023 – Funded our **£42million** screening trial, TRANSFORM

2024 – Campaigned **to update GP guidelines**

JUN 2025 – Called for an end to using the rectal exam **in diagnosis**

AUG 2025 – Campaigned to **update active surveillance rules**

There's a clear road ahead:
In the next few years, **TRANSFORM** will deliver the crucial remaining evidence and lead the way to a screening programme for all men.

In the committee's decision, there is a ray of hope. The recommendation of screening for men with BRCA gene variation is the first time they've recommended screening of any kind for prostate cancer. It shows that with definitive evidence, we can shift the dial on screening and stop men dying from this disease. What we have to do now is unlock this evidence, and at Prostate Cancer UK we have the key.

Our £42 million TRANSFORM trial will provide the science on the impact of the latest approaches to screening and show the way to an effective screening programme that can save thousands of lives each year. It's the largest and most ambitious trial of its kind in 20 years. It is backed by the NHS, the National Institute for Health and Care Research (NIHR) and the UK Government, and led by six world-leading researchers, representing four of the UK's biggest research centres. It will involve hundreds of thousands of men, run over a decade and crucially, begin delivering results in as little as two years' time, which we have already agreed the NSC will review as they become available, because we know men cannot wait.

We will not, we must not, let disappointment slow us down. Men's lives have been left to chance for far too long., and our campaigning and research is starting to turn the tide. This decision shows that we are building momentum. It shows that with the right evidence, with the science to prove that men will benefit and that lives will be saved, we can change the system and bring about a historic shift in men's health in this country.

You can support the future of screening in the UK today by donating to groundbreaking research like the TRANSFORM trial here.

prostatecanceruk.org/donate-ns

You can support the future of screening in the UK today by donating to groundbreaking research like the TRANSFORM trial here.

Together, we can build a world where no man dies from prostate cancer.

Wonders never cease

In a bad year for science, there are still plenty of marvels and whimsy to be found

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Union of Concerned Scientists
SCIENCE SAVES LIV

AARON SCHWARTZ/SIPA USA VIA REUTERS CONNECT

FROM vaccine sceptics at the heart of the US government to the continued global paralysis when it comes to climate action, science has been under siege in 2025. Those who believe in rationality and evidence must continue to fight back against the encroaching darkness – as we hope you agree *New Scientist* is doing – but also seek out the whimsy and wonder that comes from exploring the universe and everything in it.

Before we break out the party hats for the delightful celebration of science contained in our double holiday issue, it is worth reflecting on the threats we science-minded folk are facing. Wherever you turn, there are shocking examples of science being misused and abused this past year.

The gutting of US science under President Donald Trump cannot be ignored, even if you don't live in the US (see page 20). For decades, the nation has been one of the biggest funders of science in the world, to the great benefit of both the US itself and everyone else. That all changed this year. By taking an axe to US science (or, in the case of Elon Musk, a chainsaw), countless discoveries will go unmade, drugs untested and technologies undeveloped, leaving us all the poorer.

Of course, governments aren't the only source of funding, but two stories from this year demonstrate the danger of leaving science at the whim of commercial interests. Regular readers of *New Scientist* will be familiar with Colossal Biosciences, a US company that claims to be in the business of "de-extinction" (see page 24). Its most notable, or perhaps notorious, output this year were three genetically modified grey wolves named Romulus, Remus and Khaleesi.

> "While it may take time to see results, science is here to serve, save and delight us all"

Colossal claimed that these were the first living dire wolves since the species went extinct 10,000 years ago, a claim widely trumpeted by the world's media despite the protestations of independent scientists. In the battle of truth versus spectacle, spectacle seemed to take the upper hand.

A similar tale played out in November with the broadcast of the UK documentary *Hitler's DNA: Blueprint of a dictator*. There is no disputing that the scientists involved in the series have successfully identified and sequenced the Nazi dictator's genome, but the sensationalist interpretation of those results, such as claims that he may have had schizophrenia or been autistic, leaves much to be desired. While the documentary and its accompanying lurid headlines have come and gone, we still await the publication of a scientific paper detailing the work, allowing for a true assessment of the researchers' claims.

One area where we are definitely not waiting for the science is in the realm of climate action. Indeed, science and public policy have been perfectly aligned for the past decade, since nations signed the Paris Agreement pledging to keep global warming below 1.5°C. The one small problem is that we haven't actually done that.

The Paris Agreement had a "ratchet" mechanism designed to ensure we stay on track by asking countries to make new pledges on climate action every five years. Around 95 per cent of nations failed to do so by the deadline in February this year, and only about 60 per cent managed it in time for the COP30 climate summit, held in November in Belém, Brazil.

The backsliding didn't stop there. In our end-of-year leader for 2024, we called on the

Brazilian president Luiz Inácio Lula da Silva "to take to the stage and publicly admit the failure of the COP process to date, flanked by unsmiling world leaders with a clear plan to do better". Instead, countries couldn't even agree to include the phrase "fossil fuels" in the final COP30 text.

OK, OK, that's enough doom and gloom – it is the holidays, after all, so let's have some fun. Another major story of 2025 was the 100-year anniversary of quantum mechanics, which we covered extensively, including in an April special issue. To cap the year off, we have the news that a thought experiment dreamed up by Albert Einstein and Niels Bohr has finally been realised (see page 12). It shows that, yes, quantum mechanics really is that weird.

Other good-news stories from 2025 included the continued success of GLP-1 drugs in treating a range of conditions, not just aiding weight loss (see page 23), and – perhaps most whimsically of all – the people who saw a brand-new colour (see page 25).

Elsewhere in this issue, you will find an incredible smorgasbord to stuff your mind along with your stomach this holiday season. For a new twist on Charles Dickens, turn to page 46 for the story of three demons that have been haunting physicists. As you catch your breath from a busy year, consider a new approach to meditation for the time-poor (see page 58). To learn about what may be the best job in science, visit the Touch and Tickle lab on page 70. And finally, why not wash it all down with the world's oldest beer on page 50?

As we turn to 2026 and the global challenges ahead, let us remember just how powerful and wonderful science can be. Despite the sceptics and the naysayers, there is no better way of making sense of the world, and making the world a better place, than scientific inquiry and the application of knowledge it brings. While it may take time to see results – like the hundred-year gap between Einstein and Bohr's debate and the resulting experiment – science is here to serve, save and delight us all.

Here's to better luck – or at least a more beneficial draw from a random probability distribution – next year. ▮

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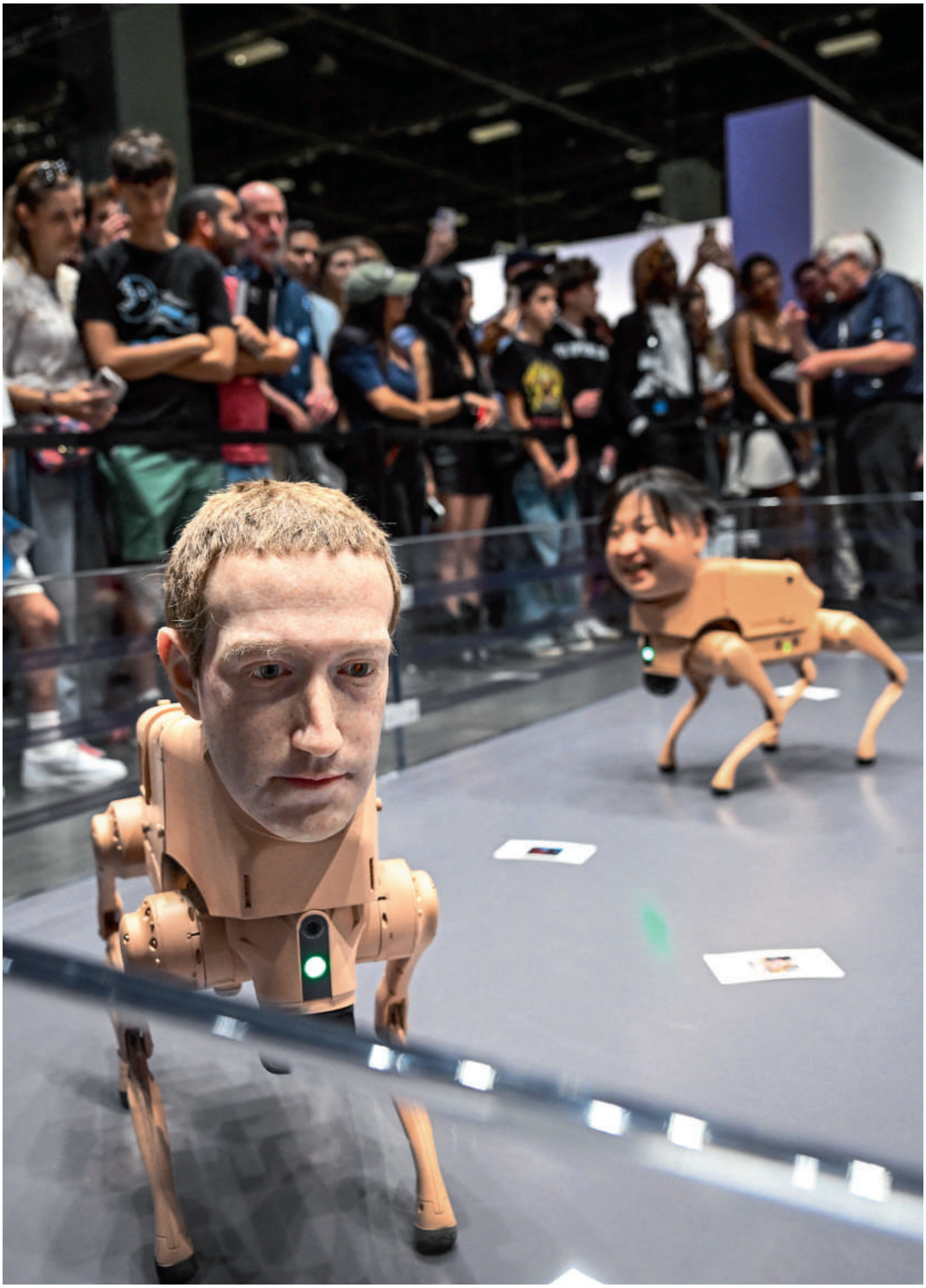


CHANDAN KHANNA/AFP VIA GETTY IMAGES

Technology

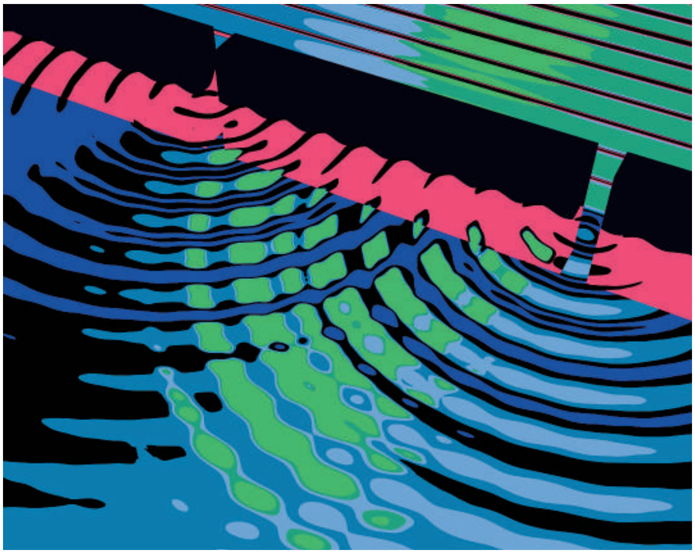
Meta's top dog gets a new look

Mark Zuckerberg was one of six real-life people to have a waxwork of his head fixed on top of a robotic dog for an installation called *Regular Animals* at Art Basel in Miami, Florida, by artist Beeple. Equipped with cameras, these dogs took pictures of what they saw, then printed them from their behind. Each image was in a different style, depending on the dog, with other figures including Andy Warhol and Pablo Picasso.

Physics

Quantum test settles an old score

By bringing to life an experiment devised by Albert Einstein, researchers may have ended a row over the true nature of quantum mechanics, reports **Karmela Padavic-Callaghan**



RUSSELL KIGHTLEY/SCIENCE PHOTO LIBRARY

The double-slit experiment was used to argue that light is a wave

A THOUGHT experiment at the heart of an argument between famed physicists Albert Einstein and Niels Bohr in 1927 has finally been made real. Its findings elucidate one of the core mysteries of quantum physics: is light really a wave, a particle or a complex mixture of the two?

Einstein and Bohr's debate concerns the double-slit experiment. In 1801, physicist Thomas Young used this test to argue light is a wave, while Einstein posited that it is actually a particle. Meanwhile, Bohr boldly proposed that it can, in a sense, be both. Einstein didn't like this idea and imagined a modified version of Young's experiment to counter it.

Now, Chao-Yang Lu at the University of Science and Technology of China and his colleagues have performed an experiment that realises Einstein's idea, to reveal that quantum objects are as peculiar in their dual wave-and-particle nature as 1920s physicists suspected. "Seeing quantum mechanics 'in action' at this fundamental level is simply breathtaking," says Lu.

In the double-slit experiment, researchers shine light onto a pair of narrow, parallel slits positioned in front of a screen. If light were a particle, the screen ought to show a blob of light behind each slit, but Young instead saw an "interference pattern" of alternating dark and light stripes. This indicated that light is more like a wave that spills through the slits, with the screen capturing its ripples clashing into each other. This interference pattern persists even when the light's intensity is reduced to a single particle of light, or a photon. Does this mean that the particle-like photon somehow interferes with itself as if it were also a wave?

Bohr argued for the notion of "complementarity" where it is impossible to see the photon's particle-ness when it is exhibiting wavy behaviour and vice versa. But Einstein imagined placing an additional slit before the usual pair that would be equipped with springs, so it could recoil when the photon entered it. Based on the springs' motion, physicists could determine which of the parallel slits the photon went through. According to Einstein, this would mean being able to simultaneously describe the photon's particle behaviour and its wave behaviour as evidenced by the interference pattern.

> **"Seeing quantum mechanics 'in action' at this fundamental level is simply breathtaking"**

Niels Bohr said light could be both a particle and a wave, but Albert Einstein disagreed

WORLD HISTORY ARCHIVE/ALAMY

Lu says his team wanted to build this device at the "ultimate quantum limit", so they shot a single photon not at a slit, but an atom that could recoil in the same way. Additionally, hitting the atom put the photon into a quantum state equivalent to a mix of moving away from the atom to the left and to the right, which also produced an interference pattern when it hit a detector. To use an atom in this way, the researchers used lasers and electromagnetic forces to make it incredibly cold, which made it possible to control its quantum properties. This was crucial for testing Bohr's retort to Einstein: he argued that the Heisenberg uncertainty principle, which says that if the change in the slit's momentum from the recoil was known very well then its position would become very fuzzy and vice versa, could destroy the interference pattern.

Finding the in-between

By tuning the lasers, Lu and his colleagues could control the uncertainty in the momentum of the atom-as-slit. In doing so, they found Bohr's assertion was correct and they could erase the interference pattern by tweaking the fuzziness of its momentum (*Physical Review Letters*, doi.org/qhc9). They also used this tunability to access a more in-between regime where they could measure some recoil information and also see a blurry version of the interference pattern. Here, the photon was effectively exhibiting both wave and particle properties at once, says Lu.

"The real interest is in [this] in-between," says Wolfgang Ketterle at the Massachusetts Institute of Technology. Earlier this year, he and his colleagues used ultracold atoms controlled by lasers to implement a version of Einstein's experiment where it is the pair of slits that can move.

Philipp Treutlein at the University of Basel in Switzerland says these experiments showcase some of the fundamentals of quantum mechanics. "With our modern understanding, we know the answer to how quantum mechanics works at the microscopic scale. But it always makes a difference if you see it for real, so to speak." ■

Health

Vaccine could offer year-long protection against allergic attacks

Chris Simms

MICE can be protected from the life-threatening allergic reaction anaphylaxis for at least a year using an experimental vaccine. The hope is that it will work in humans too.

The threat of anaphylaxis constantly hangs over hundreds of millions of people globally, with allergies to foods like peanuts or shellfish one common risk factor. In the UK, for example, around 6 per cent of adults – or 2.4 million people – are estimated to have a clinically confirmed food allergy.

Eating contaminated food, or even kissing someone who has recently eaten a food that makes you react, can cause a spike in molecules produced by the immune system called immunoglobulin E (IgE) antibodies, leading to swelling of the tongue or throat, difficulty breathing and a drop in blood pressure. In severe cases, anaphylaxis can be fatal.

Aside from attempting to avoid the allergen, options to prevent such attacks are limited. You can try oral immunotherapy, which involves consuming small, gradually increasing amounts of an allergenic food under supervision to build tolerance, or take a drug called an anti-IgE monoclonal antibody, such as omalizumab, which binds to IgE, stopping it from causing a reaction.

6%

Proportion of UK adults with a clinically confirmed food allergy

But omalizumab is expensive and needs to be injected every few weeks, potentially for life.

Now, Laurent Reber at the Toulouse Institute for Infectious and Inflammatory Diseases, France, and his colleagues have developed a vaccine named IgE-K. This primes the immune system to produce antibodies that target IgE, preventing it from binding to its receptors on immune cells and halting a subsequent runaway allergic reaction.

"We wanted to come up with a solution that could be long-term, because when you are food allergic, you can be exposed anytime by accident," says Reber.

In tests on mice modified to produce a human version of IgE, the researchers found that two doses of the vaccine induced the mice to generate neutralising antibodies against IgE.

"It blocks up the molecule that makes us allergic," says Josh Koenig at McMaster University in Ontario, Canada.

The researchers then gave the mice a substance that would cause an allergic reaction. Unvaccinated mice had a strong reaction, but vaccinated ones were protected against anaphylaxis for as long as a year without any adverse effects (*Science Translational Medicine*, doi.org/qhcn).

"It could be longer, but we haven't tested longer," says Reber.

IgE is part of the body's immune system, and as well as generating allergic reactions, it fires up in response to venoms and some intestinal parasites.

Reber says many people at risk of serious allergic reactions have received anti-IgE therapies for years without discontinuation and experienced no ill-effects. But to see whether dampening down IgE could reduce the body's effectiveness at fighting parasites, the researchers did an additional experiment in mice. They found that the vaccine didn't impair the immune response to an infection by *Strongyloides ratti*, a parasitic nematode worm.

Koenig is optimistic that such a vaccine would be effective in people. "They know that the mouse made the antibody that bound up the human IgE molecule properly. If humans make that same molecule, then I think there's a pretty high chance that this will work out quite nicely."

Still, clinical trials are needed to evaluate the vaccine's safety, efficacy and duration in humans, says Reber. ▮

Zoology

Tigers bouncing back in remote Sumatran jungle

A CAMERA trap survey has identified more than double the number of critically endangered Sumatran tigers than studies have found elsewhere on the Indonesian island.

Sumatran tigers are the last remaining population of the subspecies *Panthera tigris sondaica*, one of two tiger subspecies according to recent taxonomic assessments.

Working with the Gayo Indigenous people, researchers attached 60 sets of camera traps to trees in a previously unstudied part of the Leuser ecosystem in Sumatra, Indonesia, one of the largest intact rainforests in South-East Asia.

The traps captured images of 17 tigers over a 90-day period in 2023 and 18 tigers in 2024, while previous 90-day surveys on Sumatra spotted only seven tigers on average. In total, the survey identified 14 adult female tigers, 12 males and three sets of cubs, as well as one adult tiger of unknown sex (*Frontiers in Conservation Science*, doi.org/hbdkpf).

"It surpassed my expectations… the literature up until this study said that we weren't supposed to find tigers in these densities," says Joe Figel at the conservation organisation Hutan Harimau.

FIGEL ET AL. 2025, BKSDA-ACEH, DLHK

Camera trap photo of a Sumatran tiger in the Leuser rainforest, Indonesia

Sumatran tigers are threatened by poaching for trophies and traditional Chinese medicine, as well as logging for dipterocarp trees, a valuable hardwood.

Because of limited data, the population estimate varies from 173 to 883.

While the 90-day periods were used for comparison, the researchers ultimately surveyed for 180 days in both 2023 and 2024, which provides a more reliable record across seasons, says Deborah Martyr at the NGO Flora and Fauna International.

The higher-than-expected tiger count in the Leuser ecosystem shows the lowland forests there are rich in prey, says Figel. ▮

Alec Luhn

Immunology

The effect of tattoos on the body is more than skin deep

Christa Lesté-Lasserre

TATTOO ink collects in lymph nodes and interferes with the immune system, causing potentially lifelong changes to the body's disease-fighting mechanisms.

That is the conclusion of a study in mice, in which tattooed animals showed chronic inflammation in their lymph nodes – which were pigmented with the ink – and had altered antibody responses to vaccines. Human lymph nodes from tattooed individuals had similar inflammation and colouring.

"When you're tattooing, you're actually injecting ink into your body," says Santiago González at the University of Lugano in Switzerland. "It's not just a cosmetic effect… there are effects on the immune system as well."

Tattooing has become a global trend. Between 30 and 40 per cent of people in Europe and the US under the age of 40 have at least one tattoo.

González says he and his colleagues were working on an unrelated research project on inflammation in mice when they realised the animals developed "crazy inflammatory reactions" after being given small tattoos for identification.

To find out more, they used standard commercial inks in black, red and green to tattoo a 25-square-millimetre patch of skin on the hind feet of dozens of mice. With specialised imaging equipment, they watched the ink travel along the lymphatic vessels inside the leg up to the nearby lymph nodes almost immediately.

There, the team saw that macrophages – immune cells that clean up debris, pathogens and dead cells – captured the ink, tinting the nodes and provoking acute inflammation. Within about 24 hours, those macrophages died, releasing the ink, which then got captured by other macrophages. Those, too, would die and release ink, which would get taken up by yet other macrophages – creating a cycle of chronic inflammation that lasted well after the tattoo site had healed (*PNAS*, doi.org/qhd9).

LOXODROM
TATTOO
Loxodrom
EDEN BREITZ/ALAMY

Tattooing has now become a global trend

By the end of the experiment, two months after tattooing, the mice's lymph nodes still had levels of inflammatory markers up to five times higher than normal, says González.

"Tattooing is not just cosmetic, there are effects on the immune system as well"

To investigate whether this inflammation affected immune function, they injected vaccines directly into the tattooed skin. The tattooed mice's antibody response to a covid-19 mRNA vaccine was noticeably weaker than in control mice, but their response to an influenza vaccine was stronger.

Further analyses showed the lymph node macrophages of tattooed mice were so full of ink, they captured less of the covid-19 vaccine – which, as an mRNA vaccine, needs processing by macrophages to be functional. For the protein-based influenza vaccine, however, inflammation boosted the antibody response, perhaps because there were more immune cells recruited to the tattooed site.

Finally, they examined a small set of lymph node biopsies from people who had been tattooed in regions near the nodes. Even two years after tattooing, the nodes still contained visible pigment, packed into the same kinds of macrophages as seen in the mouse study.

Michael Giulbudagian at the German Federal Institute for Risk Assessment in Berlin says "the relevance for human health, in particular after the complete healing of the wound, must be further investigated". ■

Environment

Volcanic eruption could have led Black Death to Europe

James Woodford

THE Black Death, a bubonic plague outbreak that killed up to 60 per cent of the population of medieval Europe, may have been set in motion by volcanic activity around 1345.

The plague bacterium, *Yersinia pestis*, is spread by fleas feeding on rodents and then carried to humans bitten by infected fleas. It is unclear what led to the 14th-century outbreak in Europe, but historical sources suggest that the transport of grain from the Black Sea to Italy may have played a role.

To investigate, Martin Bauch at the Leibniz Institute for the History and Culture of Eastern Europe in Germany and his colleague Ulf Büntgen at the University of Cambridge reviewed evidence about the climate from tree ring data, ice cores and written accounts.

Observers in Japan, China, Germany, France and Italy all independently reported reduced sunshine and increased cloudiness between 1345 and 1349. This was probably the result of a sulphur-rich volcanic eruption – or several eruptions – in an unknown tropical location, say Bauch and Büntgen.

What's more, they found official records showing that, facing famine caused by the cold weather and failing crops, Italian authorities implemented an emergency plan to import grain from the Mongols of the Golden Horde around the Sea of Azov in 1347 (*Communications Earth & Environment*, doi.org/qg7x).

"Precisely because these societies practised excellent famine prevention, the plague bacterium arrived in Italy as a stowaway, carried in with the grain," says Bauch.

Perhaps population losses would have been smaller without this emergency response, says Bauch. "My argument is not against preparedness, but… an awareness that effective precautionary measures in one sphere can create problems in unexpected areas." ■

Solar system

Is this how the moon was really made?

The moon is thought to have formed during one big impact, but it could actually have been three

Jonathan O'Callaghan

MULTIPLE impacts on Earth might better explain our moon's origin than a single giant impact 4.5 billion years ago – and may help solve one of its biggest mysteries.

Pinning down the origin of our moon has been hard. The leading idea is that it was formed early in the history of the solar system in the aftermath of an impact between Earth and a giant Mars-sized object known as Theia, which possibly originated closer to the sun than where our planet is. The impact would have thrown debris into space that eventually coalesced into the large natural satellite we see today, at a time when material was more jumbled up around the sun and impacts were common.

> "After three impacts on Earth, we put enough mass into orbit to make a full moon"

But Earth and the moon are surprisingly similar in composition, which makes this model a little difficult because the moon should have retained more material from Theia than Earth. "This is a big problem for the canonical model," says Philip Carter at the University of Bristol, UK.

Instead, Carter and his colleagues propose that a chain of impacts on Earth over a few million years might better explain why Earth and the moon are so compositionally similar. They show that three or more large impacts on our planet in the early solar system, involving objects ranging from the moon's current size to nearly the size of Mars, could explain the origin of the moon we see today (*Monthly Notices of the Royal Astronomical Society*, doi.org/qg72).

In this scenario, each impact would produce a small moon, or moonlet, in Earth's orbit. Over thousands of years, these moonlets would gradually combine together under their gravity, forming one large object. "They will attract and collide with each other," says Carter. "It's very unlikely you'd end up with a stable system with multiple large moonlets."

NASA/NOAA

The moon is bigger, relative to Earth, than other satellites are to their planets

Previous models have also invoked a multiple-impact origin of the moon, but they have required a much larger number of impacts on Earth, up to 20, compared with this latest model. "After three impacts, we put enough mass into orbit to make a full moon," says Carter.

Robert Citron at the Southwest Research Institute in Colorado says that having fewer impacts "can be better" because the more impacts a model has, the more likely it is that existing moonlets would be kicked out of Earth's orbit, preventing the moon from forming. However, invoking more impacts leads to a closer compositional similarity between Earth and the moon, better explaining what we see today. "When you have multiple impacts, you're averaging more of these impactors," says Citron.

Working out how the moon formed is important because the Earth-moon system is unusual. "It's such a unique satellite," says Citron. "It's very big relative to Earth, whereas the Martian moons are very small compared to Mars, and the satellites of the gas giants are very small compared to those planets." ▮

Health

Pet pooches' microbes may make us more caring

DOGS may be man's best friend, but what if they boost our well-being by altering our microbiome? A series of experiments in mice suggests that dog owners have a unique make-up of bacterial species that encourage empathetic and social behaviours.

With dogs typically topping popular pet lists, Takefumi Kikusui at Azabu University in Japan wanted to understand whether the animals change our gut microbiome in a way that prompts good well-being.

To explore this, the researchers analysed surveys where caregivers of 343 adolescents, who were aged 12 to 14 and lived in Tokyo, reported on various aspects of their social behaviour, such as how often they felt lonely or struggled to get on with their peers. The surveys also revealed that about a third of the adolescents had a pet dog.

OISIN KENIRY/R&A/R&A VIA GETTY IMAGES

Being a dog owner can improve life satisfaction in more ways than one

The team found those with dogs ranked as less socially withdrawn and behaved less aggressively than non-dog-owners, on average.

Saliva samples also revealed that several species of *Streptococcus* bacteria were more abundant in the dog owners, which has been linked to reduced depressive symptoms.

"If you're playing with a dog a lot, you're going to have a lot of exposures to the microbes the dog has, from licks [and] them jumping up on you," says Gerard Clarke at University College Cork, Ireland.

The team then transplanted oral microbes from three dog owners and three non-dog-owners into the stomachs of germ-free mice.

Over the next few weeks, the team had the animals carry out a series of behavioural tests. In one, the mice were placed in a cage with another mouse that was trapped in a tube. The mice that received transplants from dog owners chewed the tube and poked their nose through holes in it significantly more often than those that received transplants from non-dog-owners (*iScience*, doi.org/hbdfv2).

This suggests that the former mice had more empathy and were trying to help, says Kikusui.

In another test, these same mice sniffed at an unfamiliar mouse in their cage more often than the other group, which suggests they were more social, says Clarke. ▮

Carissa Wong

Environment

Coral reefs caused historical warming

Periods when coral reef growth has peaked have coincided with big rises in sea temperatures

James Woodford

THE extent of coral reefs worldwide has played a key role in Earth's climate in the past 250 million years – but not in the way you might expect.

Coral reefs are net producers of carbon dioxide because the greenhouse gas is a by-product of the formation of calcium carbonate, which makes up corals' skeletons.

Some types of plankton also build shells out of calcium carbonate. This mineral is buried in the seabed when they die. When large areas of shallow marine environments are covered in coral, calcium and carbonate ions that would normally be taken up by deep-sea plankton is no longer available.

Tristan Salles at the University of Sydney, Australia, and his colleagues modelled the interplay between shallow-water corals and deep oceanic plankton over the past 250 million years by integrating reconstructions of plate tectonics, climate simulations and changes in sediment flowing into the sea.

They found that the balance between corals and plankton has been disrupted when plate tectonics and geomorphology lead to periods when there are extensive areas of shallow continental shelf, which is the ideal habitat for reef-building corals.

When coral reefs are less extensive, calcium and alkalinity build up in the ocean, plankton become more productive and more carbonate is buried in the deep sea, which helps lower CO_2 levels and bring temperatures down.

There were three major periods when the carbon cycle was severely disrupted in the past 250 million years, the researchers found. These events – in the mid-Triassic, the mid-Jurassic and the late Cretaceous – involved extensive coral reefs using huge amounts of calcium carbonate, leading to big rises in sea temperatures (*PNAS*, doi.org/qhd5).

When the balance between shallow-water coral reefs and deep-sea plankton breaks down, says Salles, it can take hundreds of thousands to millions of years to re-establish equilibrium. "So, even if the system manages to recover from a huge crisis, the rebalancing is going to happen over a really long time period that is much longer than human timescales," he says.

On the positive side, he says, if planktonic nutrient blooms are ever out of control, corals are great at taking up excess nutrients to build coral reefs.

Now, human CO_2 emissions are causing global warming and ocean acidification at an unprecedented rate, which is killing both corals and plankton, says Salles. The consequences are unknown, but are likely to be ecologically catastrophic, he says.

Alexander Skeels at the Australian National University in Canberra says the study shows a "deeply intertwined feedback cycle between life and climate".

People often think species evolve in response to Earth's climate, which is governed by "immutable physical and chemical processes", he says. "However, more and more often we are seeing examples where biological species directly influence the climate itself, creating a co-evolving feedback loop."

TAHSIN CEYLAN/ANADOLU VIA GETTY IMAGES

Carbon dioxide is a by-product of coral reefs forming calcium carbonate

Astronomy

Satellite trails could spoil Hubble Space Telescope images

ONE in three images taken by the Hubble Space Telescope could be ruined if space companies' plans to launch hundreds of thousands of satellites go ahead.

More than three-quarters of the nearly 14,000 satellites currently in orbit around Earth were launched in the past five years. But these numbers could be dwarfed if space companies' proposals go ahead, with as many as half a million satellites planned to launch by the end of the 2030s, according to US Federal Communication Committee (FCC) filings.

Astronomers have already raised alarm at how these satellites could affect telescopes on Earth, but now Alejandro Borlaff at NASA Ames Research Center in California and his colleagues say they could endanger space-based telescopes, too.

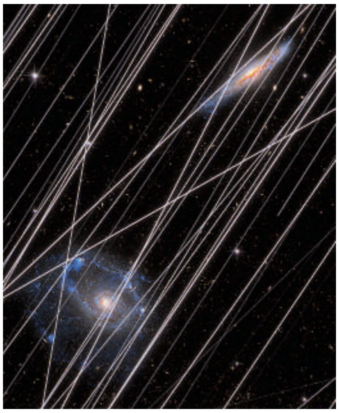
"When you position a telescope in space, it's usually a very pristine environment. You don't have any atmosphere, or city lights," says Borlaff. "Now, for the first time, you have man-made objects that are somehow polluting the images – that was very striking."

Borlaff and his team used FCC and International Telecommunication Union filings to predict how many satellites could be launched in the next decade and their planned orbits. Then they simulated how these could interfere with observations from Hubble and three other space observatories.

The researchers found that if 560,000 satellites are launched, there could be an average of two satellite trails for each Hubble photo (*Nature*, doi.org/qg7c).

They checked their simulations by predicting that with current satellite numbers, 4 per cent of Hubble images are affected by satellite trails, and this matched an analysis of real images.

Alex Wilkins


NASA/BORLAFF, MARCUM, HOWELL

This is what future space telescope images may look like, thanks to satellite trails

Solar system

Asteroid Bennu carries everything you need for life

Chris Simms

ALL the essential ingredients to kick-start life as we know it have now been found in samples from the asteroid Bennu. This shows that asteroids could have delivered all the prerequisites for life to Earth – and beyond.

In 2020, NASA's OSIRIS-REx mission extracted samples from Bennu, an asteroid that was orbiting the sun hundreds of millions of kilometres away, between Mars and Jupiter. The mission returned the samples to Earth in 2023. Since then, small amounts of the 121 grams collected have been sent out to labs across the globe for analysis.

The first studies revealed the presence of water, carbon and several organic molecules. Next came the detection of amino acids, formaldehyde and all five of the nucleobases found in RNA and DNA, as well as phosphates. However, this isn't quite enough to put together the molecules that carry genetic information. The rungs of the ladder of RNA and DNA contain a sugar, which is ribose in RNA and deoxyribose in DNA – and that was missing from the first analyses of the Bennu material.

Now, Yoshihiro Furukawa at Tohoku University in Japan and his colleagues have crushed a small share of the sample and mixed it with acid and water. Then they used gas chromatography-mass spectrometry to separate and identify the components in the mix.

This revealed the presence of ribose, as well as other sugars, including lyxose, xylose, arabinose, glucose and galactose, but not deoxyribose (*Nature Geoscience*, doi.org/qg66).

"This is a new finding of sugars in extraterrestrial materials," says Furukawa, who adds that almost all life relies on glucose in its metabolism.

"This is such a brilliant result from the OSIRIS-REx mission," says Sara Russell at the Natural History Museum in London, who also works on Bennu samples. "The one missing ingredient was the sugar, which has now been reported, so now all of the ingredients of RNA are known to be in primitive asteroids."

Furukawa and his colleagues believe that the sugars formed from brines containing formaldehyde in the parent asteroid from which Bennu came, which is thought to have carried more fluid and featured more reactions.

There is evidence for brines on Saturn's moon Enceladus and the dwarf planet Ceres, which suggests that the ingredients for life may be abundant in the solar system, says Russell.

"Now all of the ingredients of RNA are known to be in primitive asteroids"

Furukawa's work has previously detected ribose and other sugars in meteorites found on Earth, but he says there was a worry these compounds could have made their way into the rock as a result of contamination once they reached Earth. "This finding in the Bennu sample guarantees that these results were true," he says.

The new work also supports the RNA world hypothesis for the origin of life because ribose was found, but deoxyribose wasn't. This idea proposes the earliest life on Earth, long before the advent of cells or DNA-based life, consisted of RNA molecules that contained genetic information and could replicate. ▮

Health

We may know how exercise fights cancer

CREATIVEPHOTOTEAM/ALAMY

EXERCISE can slow tumour growth in mice by shifting the body's metabolism so that muscle cells, rather than cancer cells, take the glucose and grow. A similar process may occur in people.

It is well known that exercise is linked to a lower risk of cancer, but the mechanisms behind this are only partly understood. Some of exercise's influence seems to come via impacts on the community of microbes in our guts and through its effects on the immune system.

To examine another possible route, Rachel Perry at Yale School of Medicine and her colleagues have injected breast cancer cells into 18 mice – 12 of which were fed a diet that caused obesity, which worsens the progression of several types of cancer – and let half the animals run as much or as little as they wanted on an exercise wheel.

They found that after four weeks, tumours in obese mice that chose to exercise were 60 per cent smaller than those in obese mice that didn't have access to a working wheel – and also slightly smaller than those of sedentary mice fed a normal diet (*PNAS*, doi.org/hbdbnz). A 30-minute bout of exercise was tied to increased uptake of oxygen and the key energy source glucose in skeletal and cardiac muscles, and decreased glucose uptake in tumours.

Being active has long been linked to a lower risk of cancer

"This work reveals that aerobic fitness fundamentally reshapes metabolic competition between muscle and tumours," says Perry. "Importantly, the exercise intervention was voluntary. We're not talking about training for a marathon-type exercise, just what the mice wanted to do."

The researchers analysed gene activity and identified 417 genes in key metabolic pathways in mice that change as a result of exercise, essentially meaning the muscle tissues metabolise glucose more and the tumour tissues metabolise it less.

In particular, the researchers say down-regulation in cancer cells of mTOR, a protein involved in cell growth, may be restricting tumour growth.

Perry says these metabolic pathways are very similar across mammals, so she would expect the same process to happen in people.

"We need a clinical trial in people, but I really can't see any reason why you wouldn't have a similar effect in humans," says Rob Newton at Edith Cowan University in Perth, Australia. ▮ **CS**

Analysis Space

What would Russia's inability to launch crewed missions mean for the ISS?

Damage to a crucial Russian launch site means NASA may have to invest more money to keep the ISS going, or the space station could meet an early end, says **Matthew Sparkes**

THE International Space Station (ISS) may soon become slightly less international. Russia's only launch site capable of sending humans to orbit has suffered serious damage that could put it out of commission for two years. That would pose a dilemma for NASA: take on more costs and responsibility or let the ISS die.

A Soyuz spacecraft launched from Baikonur Cosmodrome in Kazakhstan on 27 November carrying two cosmonauts and a US astronaut. All three safely reached the ISS, but when engineers later inspected the pad, it was clear that a multi-level support structure that sits beneath rockets, and is usually safely stowed early in the launch process, had become dislodged and collapsed into the bottom of the flame trench, where it was damaged.

Some reports suggest repairs could take up to two years – though Russian space agency Roscosmos said in a statement the damage would be repaired "in the near future".

A deferred demise

ROSCOSMOS SPACE CORPORATION, VIA AP/ALAMY

A site in Kazakhstan was damaged after a rocket launch on 27 November

Although Baikonur Cosmodrome hosts dozens of launch pads, the affected one – Launch Pad 6 at Site 31, which dates back to 1958 – is the only one capable of sending crewed rockets to orbit. Davide Amato at Imperial College London says that Russia's other launch sites have other problems that rule out their use.

"A lot of space missions rely on single points of failure like this one, especially for programmes that are kind of winding down like the ISS," says Amato.

Indeed, the ISS's days were already numbered. Originally, it was due to have been scrapped in 2020 and has had several stays of execution. But under current plans, it will be allowed to gradually decline in altitude from next year until 2030, when a final crew will strip it of useful and historical equipment and allow it to continue its slow fall towards Earth, eventually burning up some time in 2031.

Without Russia's involvement, NASA would have to invest more money and resources to step up and keep the ISS going – a wearisome prospect even before factoring in that the project is in its final years.

But Amato doubts the US will be willing to let the ISS die just yet. Without it, the US and Europe have no destination in space for astronauts, and little reason to launch anyone to orbit until still-distant projects like commercial space stations and lunar settlements are built. This is in contrast to China, the US's main economic rival, which has a thriving space station.

"It wouldn't look good," says Amato. "And there's definitely tonnes of incredible research that is enabled by that platform, so that would be a huge loss."

When construction of the ISS began in the 1990s, there was a different geopolitical climate. The Soviet Union had fallen and there was a desire to create a project that encouraged cooperation between the two former superpowers. The ISS was carefully designed so as to not just promote cooperation, but demand it: the Russian Orbital Segment (ROS), managed by Roscosmos, provides propulsion to keep the ISS in the correct orbit and avoid danger, and the US Orbital Segment (USOS), managed by NASA and European, Japanese and Canadian space agencies, provides electrical power from solar panels. Neither part can survive without the other. But things didn't go quite so smoothly, and relations between the US and Russia have been as tense in space as on Earth – a situation that was exacerbated by Russia's invasion of Ukraine's Crimean peninsula in 2014, then its full-scale invasion of Ukraine in 2022.

> **"There's tonnes of incredible research that is enabled by the ISS, so that would be a huge loss"**

Unanswered questions

Now, if Russia were to pull out of the ISS project entirely, NASA and the other space agencies would have to ferry not only their astronauts, but also more fuel, food and supplies that Russia would have otherwise provided. There would be other tricky questions to answer too, such as whether those agencies took on official management and use of the Russian section of the ISS. NASA, given recent budget cuts, would have to ask itself if such a thing were even possible.

At the time of writing, much of the Roscosmos website was offline and the agency didn't respond to a request for comment about the extent of damage at Site 31. The European Space Agency and the Canadian Space Agency also didn't respond to a request for interview from *New Scientist*.

NASA spokesperson Jimi Russell told *New Scientist* that the agency "coordinates closely with its international partners, including Roscosmos, for the safe operations of the International Space Station and its crew members". But he declined to answer questions about the ongoing involvement of Russia or whether contingency plans were in place should it decide to sever its involvement.

There is time to assess these issues before Russia's next scheduled crewed mission to the ISS in July, but the country will need to urgently develop a plan to resolve the issues at Baikonur. ■

Health

Man unexpectedly free of HIV after stem cell transplant

Carissa Wong

A MAN has become the seventh person to be left HIV-free after receiving a stem cell transplant to treat blood cancer. Significantly, he is the second of the seven who received stem cells that weren't actually resistant to the virus.

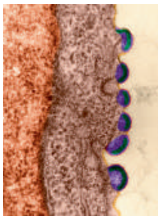
"Seeing that a cure is possible without this resistance gives us more options for curing HIV," says Christian Gaebler at the Free University of Berlin.

Five people have previously become free of HIV after receiving stem cells from donors who carried a mutation in both copies of a gene encoding a protein called CCR5, which HIV uses to infect immune cells. This led scientists to conclude that having two copies of the mutation, which completely removes CCR5 from immune cells, was crucial for curing HIV.

But last year, a sixth person – known as the "Geneva patient" – was declared free of the virus for more than two years after receiving stem cells without the CCR5 mutation – although many scientists think the roughly two-year virus-free period isn't quite long enough to show they were actually cured, says Gaebler.

The latest case strengthens the idea that the Geneva patient has been cured. It involves a man who, in October 2015, received stem cells to treat leukaemia, a type of blood cancer where immune cells grow uncontrollably. The man, who was aged 51 at the time, had HIV. During his treatment, he was given chemotherapy to destroy the vast majority of his immune cells, making room for the donor stem cells to produce a healthy immune system.

Ideally, the man would have received HIV-resistant stem cells, but these weren't available, so doctors used cells that carried one typical and one mutated copy of the *CCR5* gene. At the time, the man was taking a standard HIV therapy called antiretroviral therapy (ART), a combination of drugs that suppress the virus to undetectable levels, meaning it can't be passed on to other people – and reducing the risk that the donor cells would be infected.



SCIENCE PHOTO LIBRARY/ALAMY

A transmission electron micrograph of HIV (purple) in human lymph tissue

But about three years after the transplant, he chose to stop taking ART. "He felt that he'd waited some time after the stem cell transplant, he was in remission for the cancer, and he was always feeling that the transplant would work," says Gaebler.

Shortly after, the team found no signs of the virus in blood samples from the man (*Nature*, doi.org/hbc9w6). He has since remained free of the virus for seven years and three months, enough for him to be considered "cured".

The discovery upends our understanding of what is required for curing HIV via this approach. "We thought you needed to transplant from donors that lack CCR5 – it turns out that you don't," says Ravindra Gupta at the University of Cambridge.

However, it is important to point out that cancer-free people with HIV won't benefit from stem cell transplants, as it is a very risky procedure that can lead to life-threatening infections, says Gaebler. Most people are better off taking ART, which is a much safer and more convenient way to stop HIV from spreading, he says. Moreover, a recently available drug called lenacapavir provides nearly complete protection against HIV with just two injections per year. ▮

Archaeology

Ancient artefacts found near caves in the Arabian desert

THE dry deserts of north-eastern Saudi Arabia were once wet enough to host vibrant communities of animals – and researchers have just found evidence that ancient hominins lived there too.

The research focuses on a mostly underexplored region of the Arabian peninsula between Qatar and Kuwait. Records of a prehistoric human presence in this area are non-existent, yet scientists know it once received enough rain to support a thriving ecosystem.

"Hominins have been in Arabia for at least the last 500,000 years, probably in multiple waves of occupation," says Huw Groucutt at the University of Malta.

COURTESY HUW S. GROUCUTT, ET AL

A cave opening near a site where ancient humans may have lived in the Arabian desert

To find out more, Groucutt and his team identified ancient rivers and caves located near deposits of chert, a hard and dense rock that prehistoric humans used to make tools.

In total, they searched 79 caves and their surroundings. Several of them contained evidence of the presence of ancient humans and animals (*PLOS One*, doi.org/qg65). One cave was adjacent to a site with more than 400 stone tools scattered across its floor. Inside the caves, they also discovered the remains of ancient reptiles, bats, birds, camels, gazelles, hyenas and wolves.

By analysing the style of the stone tools, they determined that the hominins lived by the caves between 10,000 and 100,000 years ago.

"The exceptional preservation of thousands of bones in these caves provides rare insights into past ecosystems," says Monika Markowska at Northumbria University, UK. ▮

Taylor Mitchell Brown

Review of 2025

Welcome to *New Scientist*'s round-up of the biggest stories in science and technology in 2025

Under attack
It's been a tough year for science in the US **this page >**

Amazing animals
The best pictures from the animal kingdom **p22**

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Drugs like Wegovy could help with more than weight loss **p23**

De-extinction debate
Colossal Biosciences made some big claims this year **p24**

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People saw a new colour for the first time **p25**

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Media companies are taking on AI firms **p29**

Robert F. Kennedy, Jr.

THOMAS/NURPHOTO/SHUTTERSTOCK; FACING PAGE: JASON C. ANDREW/BLOOMBERG VIA GETTY IMAGES

Science policy

A year when US science was on the chopping block

The Trump administration has targeted everything from public health to space missions, reports **Chelsea Whyte**

ONE of the most enduring images of 2025 is billionaire Elon Musk, at the time serving as a special adviser to the administration of US President Donald Trump, wielding a shiny, red chainsaw as he crowed about cuts to the US federal government. It was a heavy-handed metaphor for the onslaught to come, and from cancelled space missions to a rejection of vital climate change programmes, science felt the chop.

It began in a frenzy – just a week after Trump was inaugurated in January, he signed an order to temporarily halt grants and loans made by US federal agencies. This disrupted or terminated thousands of grants overseen by the National Institutes of Health (NIH), one of the largest funders of biomedical research in the world, and the National Science Foundation (NSF). According to Grant Witness, a website tracking federal grant funding changes under Trump, the cut in grants from the NIH and NSF amount to around \$3 billion altogether.

In the months that followed, Musk led an independent task force called the Department of Government Efficiency (DOGE) on a mission to slash government spending. DOGE's targets fell across the US government, but many of its decisions affected scientists. There were job cuts at the US Centers for

"This will probably lead to more scientists leaving the US and less funding for work critical to the health of the planet"

Disease Control (CDC), NASA, the Environmental Protection Agency and the National Oceanic and Atmospheric Administration (NOAA), among many others. As recently as October, the Trump administration revealed that it planned deep cuts at the science centres of the US Geological Survey, which monitor the health of US agricultural and natural resources, and the National Park Service, which oversees federally protected land that serves as a refuge for animals and a living laboratory for biologists and ecologists.

Since the second world war, the US has invested in scientific pursuits as a path towards progress and economic prosperity. It was an idea set out by the leader of the Office of Scientific Research and Development in the 1940s, a predecessor to the NSF. This framework, called the "endless frontier", was a pioneering approach to becoming a global leader in research and development of key technologies that changed the world. Trump has brought that crashing down.

Not only has he dismantled much of the research apparatus of the federal government, but his administration has also put pressure on universities to align their teaching and research with US government priorities. And he has gone even further in his repudiation of science. To no one's surprise, Trump began the process of removing the US from the world's premier climate deal, the Paris Agreement, as soon as he took office. Later in the year, speaking at the United Nations, he called climate change "the greatest con job ever perpetrated on the world".

Not content with these proclamations, the Trump administration has axed or undermined key climate databases and reports previously created by the US government. With fewer staff at many of the science-related agencies, monthly climate reporting calls at NOAA have been cancelled, for instance, and key reports such as the US National Climate Assessment have been terminated. The employees who are left are also toeing the Trump line: for example, NOAA scientists refused to link warming weather to climate change earlier this year, to the shock of independent climate researchers.

Left: Robert F. Kennedy Jr and Donald Trump have made cuts to US health agencies

Below: Elon Musk led a task force to slash government spending

10,000

Number of layoffs at the Department of Health and Human Services

47%

Proposed cut to NASA's science budget

End of the endless frontier

US public health data has also been gutted. The scientists running the National Survey on Drug Use and Health, a crucial tracker for drug use, addiction and mental health in the US, were fired in April. A few months later, the government laid off employees at the National Health and Nutrition Examination Survey and ended reports that monitor food insecurity throughout the country, which help allocate funding for food assistance. Most recently, 100 positions at the National Center for Health Statistics were eliminated, including most of the staff who run the National Vital Statistics System, which tracks births and deaths in the US and monitors causes of deaths and maternal mortality. The National Death Index was also cut, eliminating a key source of information for public health researchers as well as those involved in long-term studies across agencies, such as the Department of Veterans Affairs.

Health policy has become particularly chaotic and evidence-free thanks to Robert F. Kennedy Jr, Trump's appointee to lead the Department of Health and Human Services. Kennedy, a long-time vaccine sceptic, has overseen the layoff of more than 10,000 people at the agency, and often clashed with public health officials, inciting a spate of resignations. He is the driving force behind the dangerous – and thoroughly debunked – claim that vaccines contribute to autism and even went so far as to promote an unfounded assertion that Tylenol (paracetamol) taken during pregnancy causes the condition. In June, Kennedy bypassed standard protocols and announced that the CDC would no longer recommend covid-19 vaccines during pregnancy or for children.

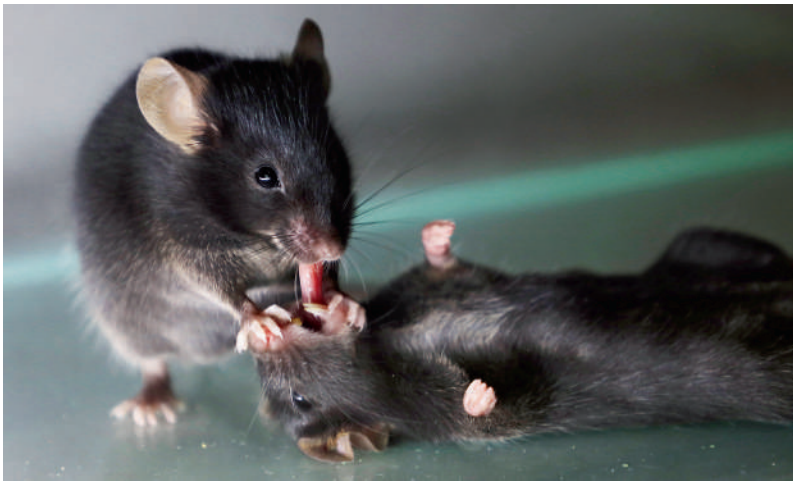
Under Trump, the US is also turning away from its leadership in space. The president's budget request, delivered in May but still not signed into law, lays out a plan to cut 47 per cent of NASA's science budget and eliminate dozens of missions, including some spacecraft and telescopes that have already been built or launched. NASA's leadership has also been in turmoil, with the head of the US transportation agency acting as administrator while Trump has nominated, rescinded his nomination and then re-nominated the billionaire Jared Isaacman for the role. A leaked manifesto written by Isaacman suggests that if confirmed as head of NASA, he would oversee a massive outsourcing of NASA science and space activity to the private sector.

Even if not all of Trump's proposed cuts go through, the haphazard and, at times, hostile manner with which the entire administration has approached science and the people who do it will probably lead to more scientists choosing to leave the US and less funding for work critical to the health and well-being of people and the planet. The end of the endless frontier has diminished the US's global standing, and its effects will reverberate for many years or even decades to come. ▮

Zoology

Surprises from the animal kingdom

From a mouse giving first aid to cuckoo confrontations, here are a few of the best animal pictures from the past 12 months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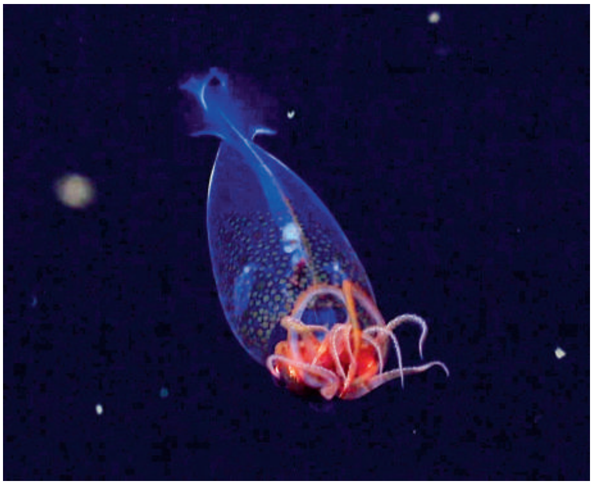
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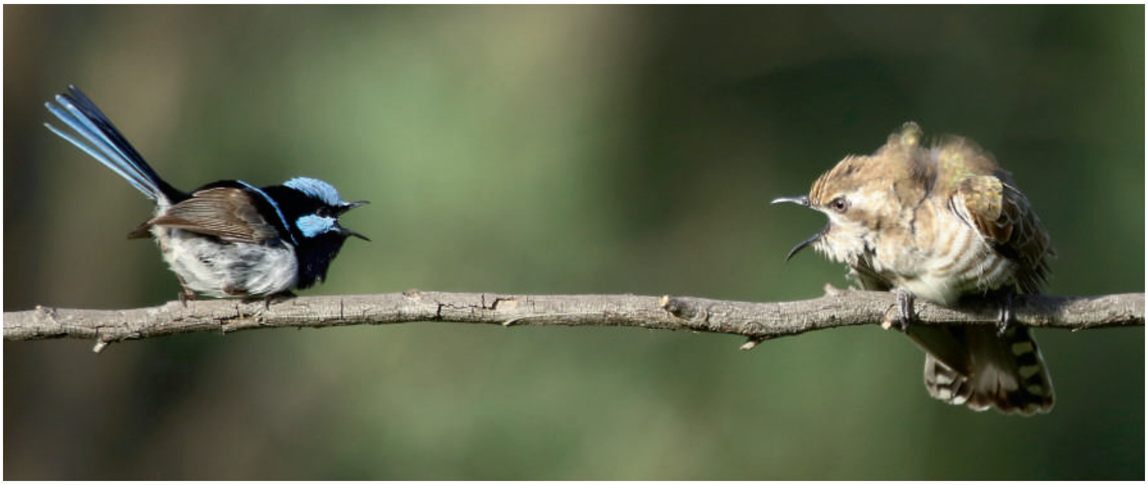
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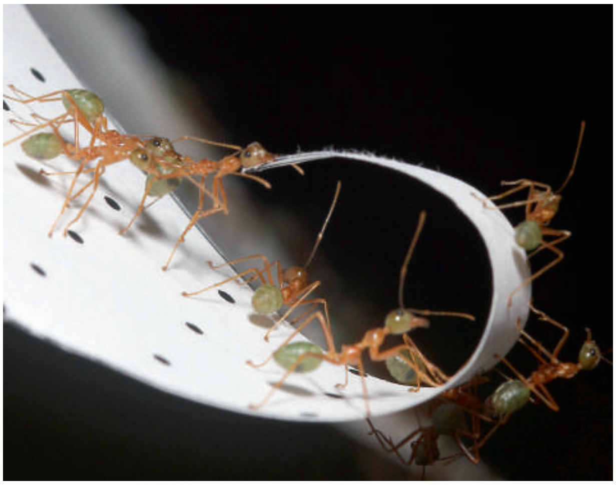
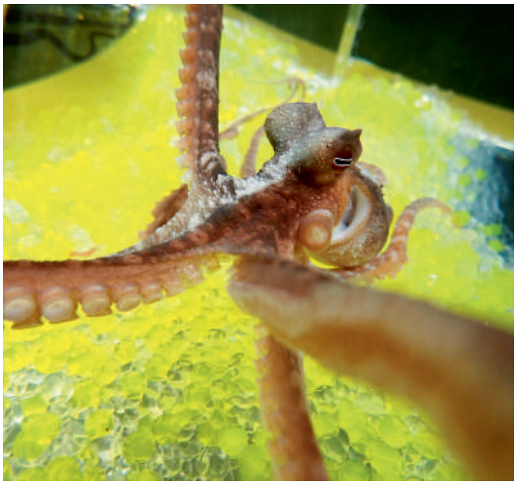

DR CHRIS REID, MACQUARIE UNIVERSITY


SUMIRE KAWASHIMA AND YUZURU IKEDA/THE UNIVERSITY OF THE RYUKYUS

Top row, left to right: One mouse resuscitates another by pulling out its tongue; the first confirmed image of a colossal squid (*Mesonychoteuthis hamiltoni*) in the deep

Middle: Superb fairy-wrens (*Malurus cyaneus*, left) were one of 20 bird species found to use the same anti-cuckoo call

Bottom, left to right: Weaver ants (*Oecophylla smaragdina*) show their strength by folding a piece of paper; this plain-body octopus (*Callistoctopus aspilosomatis*) was tricked into thinking a fake arm was its own

Health

We uncovered the true potential of GLP-1s

Drugs like Ozempic were shown to treat addiction and even slow ageing

Helen Thomson

PREVIOUSLY hailed – or derided – as weight-loss aids for the rich and famous, drugs such as Mounjaro, Wegovy and Ozempic took on a far more expansive role in 2025. No longer just considered treatments for obesity and type 2 diabetes, Ozempic gained approval in the US for treating kidney and cardiovascular disease. But far from stopping there, evidence these drugs could transform almost every corner of medicine truly exploded this year.

There were already hints the drugs, which mimic a gut hormone called glucagon-like peptide-1 (GLP-1), could do far more than just manage diabetes and obesity, with studies in 2024 suggesting they reduce the risk of heart attack and stroke, ease depression and anxiety and even slow cognitive decline.

At first, many assumed this was a simple side effect of weight loss, given obesity is a major risk factor in so many conditions. But by early 2025, it was clear something else was going on. More detailed studies showed that people were seeing benefits to their health independent of how much weight they lost.

Researchers began to discover how GLP-1 drugs act on multiple pathways, including several tied to inflammation. They also appear to influence metabolism and brain circuits involved in motivation, reward and mood, which could explain their emerging benefits for alcohol dependency and depression.

Until recently, much of this evidence came from animal experiments or observational studies. But 2025 saw a wave of larger, randomised trials examining the drugs' broader effects.

In January, researchers reported that people with diabetes taking GLP-1 drugs alongside standard treatment had a lower risk of 42 conditions – including dementia and muscle pain – compared with those on the standard therapy alone. It wasn't all good news: they were also linked to a raised risk of 19 conditions, including kidney stones, but overall the benefits outweigh the harms.

Some of the most striking discoveries from the past year concern the brain. The suspected link between GLP-1 drugs and reduced addictive behaviour gained support from the first randomised clinical trial testing the idea directly.

Semaglutide Injection Wegovy
1mg
STEP UP
1.7mg
STEP UP
2.4mg
STAY

DHIRAJ SINGH/BLOOMBERG VIA GETTY IMAGES

Drugs like Wegovy could do far more than help people lose weight

In a nine-week study of 48 people with alcohol use disorder, those given semaglutide – the drug in Ozempic and Wegovy – drank less and reported fewer cravings than those given a placebo. "We're very excited about the progress being made," says Tony Goldstone at Imperial College London. "We don't have many drugs for addiction, and [GLP-1 drugs] are already licensed for other conditions, so we know they are reasonably safe."

Other cognitive benefits also revealed themselves this year. In April, a meta-analysis of 26 clinical trials involving more than 160,000 people found that GLP-1 drugs significantly reduced the risk of all types of dementia. This followed a trial led by Paul Edison, also at Imperial College London, showing that treating people with Alzheimer's disease for a year with the GLP-1 drug liraglutide – found in the branded medications Saxenda and Nevolat – halved brain shrinkage and slowed cognitive decline by 18 per cent compared with a placebo.

> **"This Swiss Army Knife of a drug class will no doubt yield more revelations in 2026, as we find out where its limits truly lie"**

Edison believes that Alzheimer's arises from overlapping pathological processes, rather than having a single cause. GLP-1 drugs may work by acting on several of these, he says, by protecting neurons through kinase pathways, which are vital for cells' stress response; reducing cell damage by improving insulin sensitivity; and dampening inflammation.

But the good news didn't end there. Later in April, GLP-1 drugs became the first pharmaceutical treatment to show clear benefits for people with a severe form of non-alcoholic fatty liver disease, where fat accumulation triggers inflammation and scarring that can lead to cirrhosis and cancer.

Even ageing came into the picture. In a small trial of people with a complication of HIV that accelerates ageing, those receiving Ozempic injections for 32 weeks were, on average, 3.1 years biologically younger by the end of the study, compared with no change in the placebo group.

Varun Dwaraka at diagnostics company TruDiagnostic in Lexington, Kentucky, who worked on the study, again emphasises that the effects aren't just a product of weight loss. "While weight loss may seem part of the biological ageing story, the early evidence, along with what is known about GLP-1 biology, suggests there is an independent layer of metabolic improvements, which is converting to improved biological age," he says.

And there is no sign of a slowdown. Towards the end of the year, studies linked GLP-1 drugs to improvements in age-related cataracts, psoriasis and even the renewal of vital immune-supporting stem cells.

This Swiss Army Knife of a drug class will no doubt yield more revelations in 2026, as researchers work to untangle how one type of treatment can influence so many conditions – and where its limits truly lie. ▮

Gene editing

De-extinction didn't live up to the hype

Biologists poured cold water on Colossal Biosciences' claim to have brought the dire wolf back

Michael Le Page

COLOSSAL BIOSCIENCES, which calls itself "the world's first and only de-extinction company", generated a lot of headlines this year. The hype, however, bore little relation to reality.

First, the US-based firm made a splash with woolly mice "engineered to express multiple key mammoth-like traits". Victoria Herridge at the University of Sheffield, UK, pointed out on Bluesky that the long hair of the mice whose photos were splashed all over the media wasn't a result of gene edits based on mammoth DNA, and that geneticists have been creating long-haired mice for decades. The mice with more mammoth-related gene edits looked less mammoth-like.

"People have believed these claims, but it is extremely hard to tell how this will play out in the long term for conservation efforts"

Then came the big one: the world's first de-extinction, according to the company's press release. Colossal claimed it had brought back the dire wolf (*Aenocyon dirus*), a wolf-like beast that lived in the Americas before going extinct around 10,000 years ago.

COLOSSAL BIOSCIENCES

One of Colossal Biosciences' "dire wolves" (top) and some genetically engineered woolly mice (right)

In fact, what Colossal did was make 20 small changes to the genome of grey wolf (*Canis lupus*) cells, only 15 of which were based on the genome of dire wolves, and then cloned the altered cells to produce three wolf pups.

As there are millions of genetic differences between the two species, this is a tiny step towards making grey wolves more like dire wolves. It is a very, very long way from the *Jurassic Park*-style creation of exact genetic copies of extinct species. Most media outlets reported the de-extinction claim unquestioningly. *New Scientist* was one of very few to flatly reject it.

Colossal's chief scientist, Beth Shapiro, tried to justify the de-extinction claim on the basis of appearance. "We are using the morphological species concept and saying, if they look like this animal, then they are the animal," she told *New Scientist* on 7 April.

But even leaving aside the genetic differences, it isn't clear the cloned grey wolves do resemble the extinct animal. "There is no evidence that the genetically modified animals are phenotypically distinct from the grey wolf and phenotypically resemble the dire wolf," an expert group on canids from the International Union for Conservation of Nature declared in April.

In a second interview with *New Scientist*, even Shapiro herself seemed to concede the point. "It's not possible to bring something back that is identical to a species that used to be alive. Our animals are grey wolves with 20 edits that are cloned," she said.

In response to our story quoting Shapiro, Colossal put out a statement reiterating its claim: "With those edits, we have brought back the dire wolf."

Outside of those who work for Colossal, however, *New Scientist* isn't aware of any biologists who think the dire wolf has been revived.

"To my knowledge, there is no support for calling these transgenic grey wolves dire ones," says Vincent Lynch at the University at Buffalo, New York.

Lynch and others worry the belief that extinct animals can be brought back will undermine support for conserving endangered species.

De-extinction or distraction?

"People have absolutely believed these claims, but it is extremely hard to tell how this will play out in the long term for conservation efforts," says Herridge.

In July, Colossal claimed it would bring back the moa, a flightless bird from New Zealand. Critics, including Nic Rawlence

COLOSSAL BIOSCIENCES

at the University of Otago, New Zealand, said the best the company would be able to do is create a "Franken-moa" that might look a bit like the extinct bird.

Meanwhile, Rawlence, Lynch, Herridge and other critics of Colossal's de-extinction efforts found themselves on the end of a mysterious smear campaign the company says it has no involvement in. Anonymous blog posts and videos attacking their expertise and credentials appeared online. Lynch says this ended after a *New Scientist* report on 31 July, but another piece attacking Rawlence appeared on 5 September, while Herridge has seen one more dubious article.

Richard Grenyer at the University of Oxford thinks talk of de-extinction is a distraction from the bigger issues raised by our growing ability to make extensive changes to animals' genomes. "We probably need to have another discussion as a society about what we will tolerate and what we won't," he says. ▮

Technology

People saw a new colour for the first time

Carissa Wong

IN APRIL, a team of researchers reported that a device enabled them to witness an intense green-blue colour that had never been seen by humans before. After the announcement, they were bombarded by requests from the public to see the colour for themselves.

The device could enable people with some kinds of colour blindness to experience typical vision, and could even allow people with typical vision to perceive a wider range of hues. "We're very interested in expanding the dimensions of the colour experience," says Austin Roorda at the University of Waterloo in Canada.

> "We're very interested in expanding the dimensions of the colour experience"

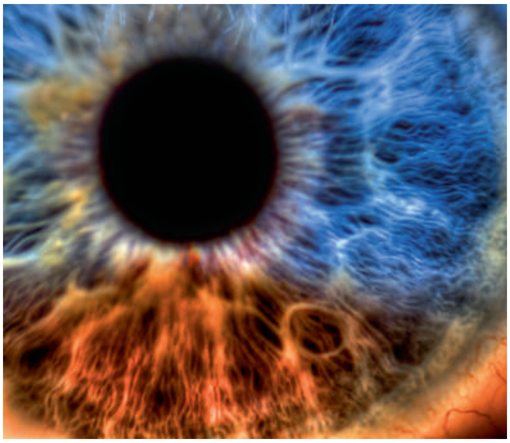
In most people, the retina at the back of the eye contains three types of cone cells – called S, M and L – that each detect light with a different range of wavelengths. Our brains create our perception of colour based on the signals from these three types of cones.

The range of the visible spectrum detected by M cone cells overlaps with the ranges of the other two types, so we don't normally receive signals from the M cells alone.

Roorda and his colleagues used an extremely precise laser to specifically activate about 300 M cones in a small square patch of the retina. This patch corresponds with a part of the visual field equivalent to the size of your fingernail at arm's length, says Roorda.

When five of the researchers used the device, they saw a blue-green colour that was more intense than anything they had seen before, which they named "olo". This was verified using a colour-matching test where they compared olo with the full spectrum of shades in the visible spectrum.

"That was really quite a stunning moment," says Roorda, who has seen olo more times than anyone else, owing to his key role in developing the system. "The most saturated natural light just looked pale by comparison."



LAURA COBB/ALAMY

Activating certain cells in the retina revealed an intense blue-green colour

After the achievement made a splash in the media, the team received dozens of requests from people – including artists – to view olo. But it takes several days to get the system set up for a new person, so the team couldn't afford to accept these, says Roorda.

Instead, the researchers are focusing on two ongoing experiments. In the first, they will test whether the device could enable people with colour blindness to temporarily experience typical vision. Certain kinds of colour blindness are caused by only having two types of cones rather than three. "We would play some of the cones belonging to a single cone type a little differently to others of that cone type, and we think this will send signals to the brain as if they had a third cone type," says Roorda. The hope is people's brains will interpret those signals as new colours they haven't perceived before, he says.

The team is also exploring whether a similar approach could allow people with three cone types to experience the world as if they have four, which some people have naturally, enabling them to see a wider range of hues. Results from both experiments should be available next year, says Roorda. ▮

Climate change

China's emissions may have finally peaked

The world's biggest emitter of carbon dioxide is on the cusp of a major turning point

James Woodford

THIS may be the year that China's greenhouse gas emissions begin a long-term downward trend – but right now, that landmark is still hanging in the balance.

China is the world's largest emitter of carbon dioxide and has set a target of 2030 to see its emissions start to decline, a turning point regarded as critical if the world is to avert a climate catastrophe in coming decades.

After the first three quarters of 2025, it is too close to call whether the full year will see a slight increase or a slight decrease, according to an analysis by Lauri Myllyvirta at the Centre for Research on Energy and Clean Air in Finland for Carbon Brief.

China's total emissions have been flat or falling slightly since March 2024. The rapid growth of solar and wind power generation is the main force bringing emissions down, but fossil fuel demand has risen in other sectors, says Myllyvirta.

"Emissions from the power, cement and steel sectors are down, but the chemical industry has seen another major increase in coal and oil consumption," he says.

In January to August, electricity demand grew by 320 terawatt hours, a 4.9 per cent rise compared with the same period last year. Offsetting this, solar generation grew by 250 TWh, wind by 105 TWh and nuclear by 30 TWh, a total increase of 385 TWh from the three non-fossil sources.

Solar panels cover the hills of the village Hangkeng in Ganzhou, China

ZHU HAIPENG/VCG VIA GETTY IMAGES

> **"If China's emissions do start to fall, we can expect the global trend to head in the same direction"**

The pace of solar growth in China has been astonishing, says Myllyvirta. "In the first half of 2025, solar power capacity additions were equivalent to 100 solar panels installed per second," he says. "Solar power capacity added was 240 gigawatts in the first nine months of the year, up 50 per cent year on year. That capacity addition in just nine months is more than the US total installed capacity."

The trade tariffs imposed by US President Donald Trump have so far had no discernible impact on China's emissions, says Myllyvirta, with positive and negative forces from the trade war largely cancelling each other out.

If China's emissions do start to fall, we can expect the global trend to head in the same direction, says Li Shuo at the Asia Society Policy Institute in Washington DC. "However, I would caution against declaring a peak prematurely, as we need data from the next few years to confirm the trend," he says.

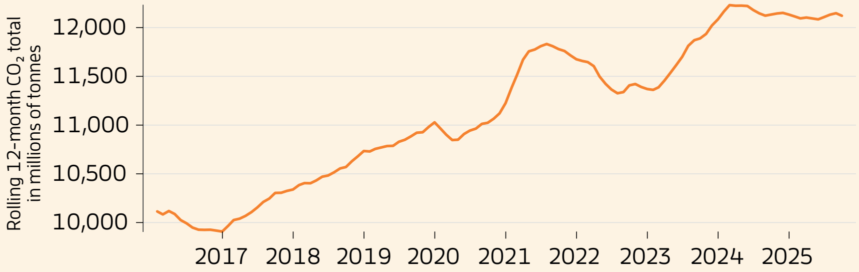
"The future of the Paris Agreement's temperature targets depends on how quickly China and developed nations accelerate emissions reductions, as well as how developing countries manage to curb emissions while fostering economic growth," says Li.

David Fishman at the Lantau Group, a consultancy based in Hong Kong, says it appears emissions will be down for the year, but he also cautions against early optimism. "Anything could happen in the last few months of 2025," he says. "Power consumption growth has been met 100 per cent and then some by low-carbon sources, which has arrested and even very slightly reversed the growth of emissions in the power sector."

Even if China has reached the peak ahead of its 2030 target, it is unlikely that emissions will decline rapidly in the next five years, says Fishman, because Chinese consumers haven't yet hit the per capita energy use of high-income nations. "I think we're likely to see flat Chinese emissions until 2030 still, and no real decline until post-2030." ▮

A turning point

China's carbon dioxide emissions are flatlining after rising for years



SOURCE: ANALYSIS FOR CARBON BRIEF BY LAURI MYLLYVIRTA

Space

An asteroid threatened to hit Earth, then the moon

Alex Wilkins

THE chances of a devastating asteroid impact briefly spiked in 2025, after astronomers discovered a building-sized asteroid hurtling towards Earth.

The asteroid, named 2024 YR4, was first detected by astronomers in late December 2024 and was estimated to be between 40 and 90 metres wide. Its possible trajectories across our solar system passed through a narrow window that contained Earth, with astronomers calculating at the time that it had a 1-in-83 chance of striking the planet in 2032.

"If it was to collide with the moon, it would be a wonderful opportunity to learn about the impact process"

As they made more detailed observations of the asteroid's trajectory during the first months of 2025, astronomers calculated increasingly likely chances of impact, reaching its most perilous level of a 1-in-32 chance at the beginning of February.

If the hypothetical impact had been near a city, the aftermath would have been devastating, releasing the equivalent of megatonnes of TNT. The asteroid was deemed dangerous enough that it was briefly designated as a 3 on the 10-point Torino rating system of likely impact consequences, in which 0 means there will be no consequences and 10 means it will cause a global catastrophe. It also triggered several United Nations-affiliated bodies to take further action, such as coordinating global telescope observation campaigns and meeting to decide whether an asteroid-deflection mission might be needed.

During this time, the world's space agencies regularly met and coordinated to compare notes on their observations and to try to better understand the asteroid. "2024 YR4 was a great teacher to us," says Richard Moissl at the European Space Agency (ESA). "This was great training that improved our [asteroid detection] methods and our understanding of the whole matter."

By 20 February, astronomers had sufficiently honed 2024 YR4's orbit to nearly entirely exclude Earth from the window the asteroid would pass through, and ESA swiftly downgraded the risk of an impact to a 1-in-625, or 0.16 per cent, chance. Some weeks later, both NASA and ESA announced there was no chance of an impact at all. "It's not perceived as a threat for Earth," says Moissl.

Lunar landing

However, astronomers haven't been able to rule out a possible impact on the moon, with the current risk sitting at around 4 per cent for 2032. "If it was to collide with the moon, it would be a wonderful opportunity to learn about the impact process and to witness it from a kind of safe distance," says Gareth Collins at Imperial College London.

Scientists have begun calculating the possible consequences of a moon impact, such as the asteroid launching a shower of satellite-destroying shrapnel towards Earth, as well as whether a deflection mission might be possible and what might be the most effective strategy to employ, from firing small satellites into the asteroid to blowing it up with a nuclear bomb. "You would want to do that very, very carefully, so that you don't turn a moon impact into an Earth impact," says Moissl.

Our imprecise figure of a 4 per cent chance of a moon impact isn't currently high enough to make the world's space agencies seriously plan a mission. That figure is also unlikely to change soon, because 2024 YR4 is currently behind the sun and so isn't visible to telescopes – and it won't reappear until 2028.

But we will have one rare chance to view it in February 2026 with the James Webb Space Telescope, because of its unique vantage point in orbit around Earth. Data from these observations will be our final realistic chance to decide whether we want to launch some sort of mission to visit or deflect the asteroid, says Moissl, because designing an asteroid mission can take many years. ▮

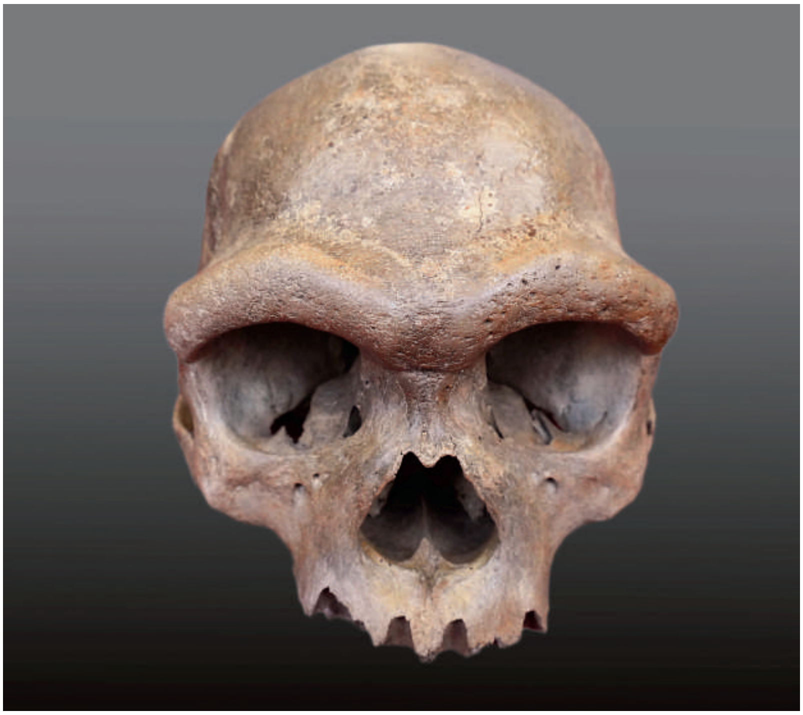
Asteroid 2024 YR4 began worrying astronomers in 2025

NASA/MAGDALENA RIDGE 2.4M TELESCOPE/NEW MEXICO INSTITUTE OF TECHNOLOGY

Archaeology

New twists in our human story

Here's a selection of some of the most incredible archaeological discoveries of the year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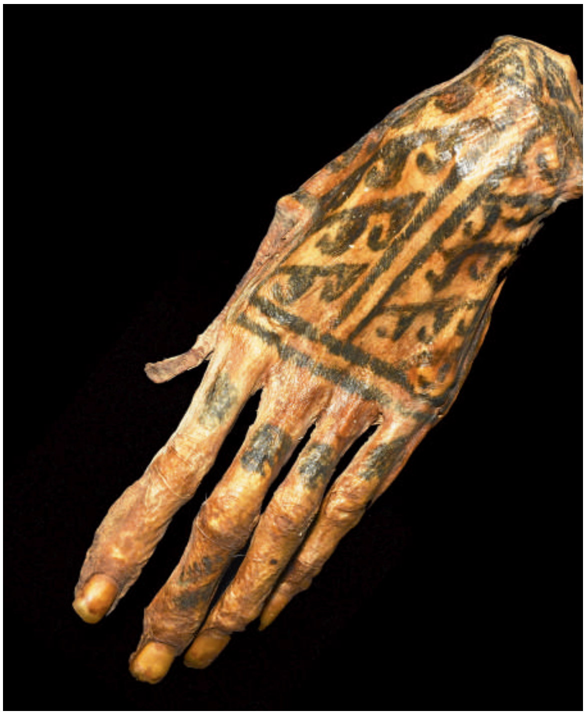
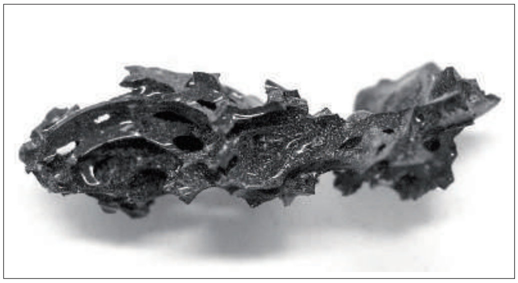

MICHAEL PITTMAN AND THOMAS G KAYE

Top row, left to right: A skull unearthed in Harbin, China, was confirmed to belong to a Denisovan; tattoos found on the hand of a 1200-year-old mummy

Middle, left to right: Glass that formed from the remnants of a man's brain following the eruption of Mount Vesuvius in AD 79; the skeleton of a man from Huiyaotian in Guangxi, China, whose remains were smoke-dried prior to burial more than 9000 years ago

Bottom, left to right: A 30,000-year-old stone tool found in the Czech Republic in the kit of a hunter-gatherer; the skeleton of an Anglo-Saxon woman with a baby in her left arm discovered in Scremby, UK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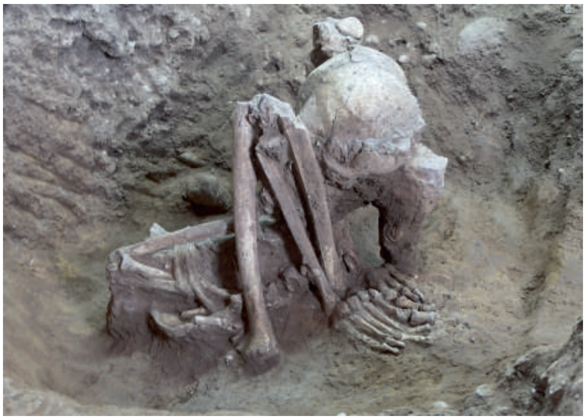
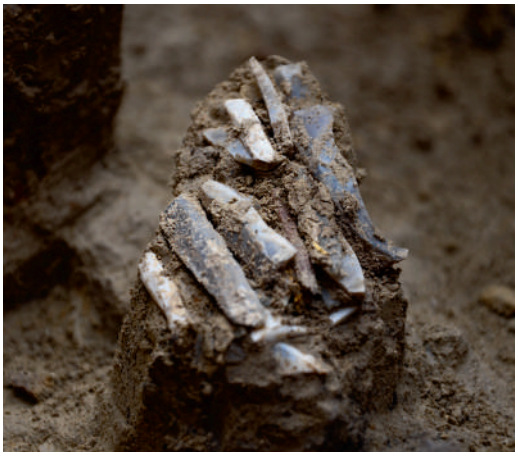
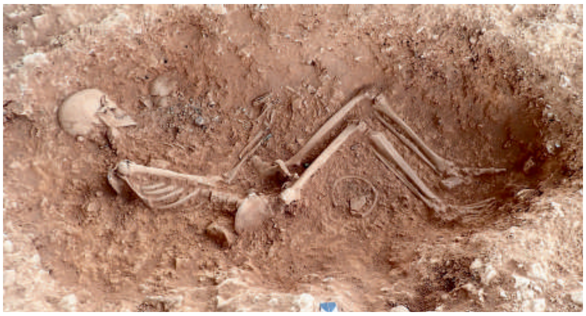

YOUSUKE KAIFU AND HIROFUMI MATSUMURA


MARTIN NOVÁK


DR HUGH WILLMOTT, UNIVERSITY OF SHEFFIELD

Artificial intelligence

AI firms felt the wrath of copyright holders

How media companies tried to wrestle back control of their characters from AI models

Chris Stokel-Walker

THE three years since the release of ChatGPT, OpenAI's generative AI chatbot, have seen huge changes in every part of our lives. But one area that hasn't changed – or at least, is still trying to maintain pre-AI norms – is the upholding of copyright law.

It is no secret that leading AI firms built their models by hoovering up data, including copyrighted material, from the internet without asking for permission. This year, major copyright holders struck back, buffeting AI companies with a range of lawsuits alleging copyright infringement.

The most high-profile case was filed in June by Disney and Universal, both of which alleged in a lawsuit that AI image generator Midjourney had been trained on their intellectual property, allowing users to create images that "blatantly incorporate and copy Disney's and Universal's famous characters".

That case is still ongoing, with Midjourney responding in August that "the limited monopoly granted by copyright must give way to fair use", which would allow AI firms to train their models on copyrighted works because the outcomes are transformative – that is, sufficiently different to avoid breaching copyright.

Midjourney's fighting words highlight how the copyright argument isn't as simple as it may seem at first. "Many people thought that copyright would be the silver bullet that killed AI, but it is not turning out that way," says Andres Guadamuz at the University of Sussex in the UK. Guadamuz says he's surprised at how little of a dent copyright is making on AI companies' progress.

Governments get involved

That is despite some governments stepping into the debate. In October, the Japanese government formally asked OpenAI, the company behind the Sora 2 AI video generator, to respect the intellectual property rights of its culture, including manga and popular video games such as those published by Nintendo.

Sora 2 has faced further controversy due to its ability to create lifelike footage of real people. OpenAI strengthened its limitations on depicting Martin Luther King Jr after representatives of his estate complained that the civil rights campaigner was being depicted in pastiches of his famous "I have a dream" speech, including one where he made monkey noises.

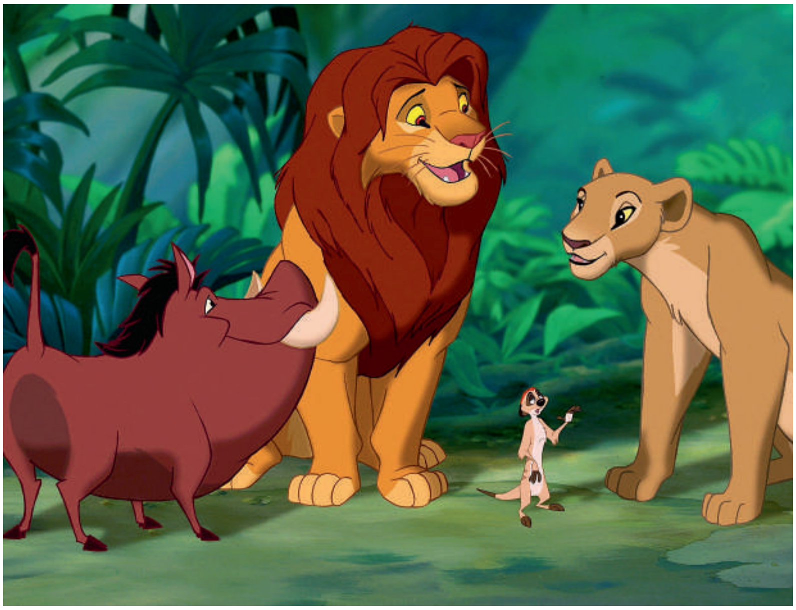
"While there are strong free speech interests in depicting historical figures, OpenAI believes public figures and their families should ultimately have control over how their likeness is used," the firm said in a statement. The climbdown was only partial: celebrities or public figures have to opt out if they don't want their images to be used in Sora 2, which some see as overly permissive. "No one should have to tell OpenAI if they don't want themselves or their families to be deepfaked," says Ed Newton-Rex, a former AI executive and founder of campaign group Fairly Trained.

In some instances, AI companies have faced legal actions for their activities, as seen in one of the biggest putative lawsuits of the past year. In September, three authors alleged that Anthropic – the company behind the Claude chatbot – had knowingly downloaded more than 7 million pirated books in order to train its AI models.

A judge assessing the case deemed that, if the firm had used this material to train its AI, it wouldn't have inherently breached copyright, since training these models would have been a sufficiently "transformative" use. The allegation of piracy, however, was deemed serious enough that it could go to trial. Rather than doing so, Anthropic chose to settle the case for a minimum of $1.5 billion.

"The takeaway is that AI firms appear to have made their calculations and will probably end up paying a combination of settlements and strategic licensing agreements," says Guadamuz. "Only a handful of companies will go out of business as a result of copyright infringement lawsuits," he says. "AI is here to stay, even if many of the existing companies do not make it due to lawsuits or because of the bubble." ▮

"AI is here to stay, even if many of the existing companies do not make it due to lawsuits"



MAXIMUM FILM/ALAMY

Disney alleged that AI image generator Midjourney was trained on films like *The Lion King*

IT'S A NO TO FULL PROSTATE CANCER SCREENING

WS • BREAKING NEWS • BREAKING NEWS • BREAKING NEWS • BR

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Aperture
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Making sense of quantum cause and effect p41

Columnists

Diving back into 2025

From ancient humans to AI slop, and from comets to cold-water exposure, our columnists look back on the year we've just had

How I learned to keep my brain in better repair

Neuroscience columnist Helen Thomson on small changes that made a big difference to her health this year

ELAINE KNOX

I HAVE come to realise that my day is littered with small rituals. Each morning, I stir a spoonful of creatine into my water, drink it to wash down a multivitamin, then eat some plain but bacteria-laden yogurt. Across the table, my kids eat homemade cereal, drink kefir and attempt to speak Spanish using Duolingo. After the school run, I plunge into a cold pond, then thaw in a sauna before work. Later, I always add a spoonful of sauerkraut to my lunch and never miss an opportunity for a quick walk around the park.

It's all a bit sickening, on reflection. Very "wellness influencer meets midlife neuroscientist". But this domestic bliss is a far cry from a year ago, when the kids were chugging Coco Pops and I was fuelled on caffeine, glued to my computer, barely glimpsing daylight.

My smug new life is a direct result of spending all year exploring evidence-based ways to keep the brain in good repair – from boosting cognitive reserve to cultivating a healthy microbiome. Now, as I take stock, I can see that small changes have made a profound difference.

One of the simplest lessons came from JoAnn Manson at Brigham and Women's Hospital in Massachusetts, who sent me details of a huge trial of older adults showing that a daily multivitamin slowed cognitive decline by more than 50 per cent. When I asked other experts what supplements, if any, might also boost brain health, creatine stuck with me – it provides the brain with an energy source when it needs it most.

But the biggest change wasn't on our supplement shelf, but in our weekly shopping basket. Chatting to neuroscientists and nutritionists convinced me of the importance of continually caring for our microbiome. So my family started doing just that: eating three types of fermented foods a day on epidemiologist Tim Spector's advice, removing ultra-processed foods from breakfast and making sure we get a diverse mix of whole foods into our diets.

I have never needed much of an excuse to throw myself into a cold lake or sit in a sauna, but science has given me plenty of reasons to prioritise those activities this year. Cold and hot exposure can reduce inflammation and stress, and boost connectivity between networks in your brain that are responsible for controlling emotions, decision-making and attention, potentially explaining why they are linked to better mental health.

Getting outside has also become a family priority. Gardening, I have learned, can boost the diversity of our beneficial gut bacteria, while walking through woods may benefit memory and cognition and protect against depression.

Back home, we are persevering with Duolingo, not just for the linguistic benefits, but also for our cognitive reserve – the brain's defence against conditions of ageing. I am building mine in other ways too, playing the piano for the first time in years. As I stumble through my scales, I remember what Ellen Bialystok at York University in Canada told me: "What's hard for the brain is good for the brain."

The most astonishing thing is just how quickly results showed. While some habits are longer-term investments into cognitive health, others, I am convinced, have had immediate impacts: calmer children, less brain fog, more energy. Perhaps it's a placebo, but something is working.

Next year, I will keep experimenting. Here's to another year of finding simple ways of keeping your brain thriving. Now, where did I put that kombucha?

Comets were on fire this year – for better or worse

Field Notes from Space-Time columnist Chanda Prescod-Weinstein on how comets grabbed the headlines in 2025

I DON'T think anyone declared it, but 2025 was a big year for comets. There was comet Lemmon, which was discovered in January and stayed in the news for a good nine months. The images of Lemmon's long and beautiful tail, created by solar heating of the comet, stopped me in my tracks every time.

Then there was the September discovery of C/2025 R2 (SWAN), a comet so bright that even when it was near the moon on Halloween, it was still quite visible to observers. And there was comet 3I/Atlas, which became famous because an astronomer at Harvard University whose main area of expertise is cosmology declared it was an alien probe.

As a cosmologist who knows she isn't an expert on comets, I believe all of the experts who say that, without a doubt, comet 3I/Atlas isn't an alien object. This shouldn't be disappointing. The comet is still scientifically fascinating. It is different from Lemmon and SWAN because it has origins outside of our solar system. Comet 3I/Atlas is, by definition, interstellar.

Its arrival in our solar system makes it an exciting opportunity. By studying its composition, we can learn a lot about its home star, even though it is impossible to reverse engineer its exact trajectory. In other words, we can learn about a mystery star's composition, even if we don't know which star we are studying.

Our journey with comets this year is only the latest in a long arc of human reactions to mysterious celestial objects appearing in the sky. Perhaps most famously, the passage of Halley's comet in 1066 was depicted in the Bayeux Tapestry as signalling the start of the Norman invasion of England. Today, we know that humanity isn't the centre of the universe – and that the universe doesn't have a centre – but I could forgive someone for momentarily thinking that 2025's comets are trying to tell us something.

As we look back on the year, so many scary and disappointing things happened that it can be easy to think these comets might have heralded the end of the world as we know it. US science is up against the ropes as the current administration cancels grants and programmes (see page 20). In both the US and the UK, attacks on immigrants have become more mainstream.

As a Black and Jewish queer scientist and child of immigrants, keeping heart is a daily challenge for me. I am aware there are people who want me silenced. Against all my scientific training, I could choose to read the comets as a sign that I should give in. But there is another option: I can witness, as a scientist, the way that the comets hold hope for me. They are a beautiful visual sanctuary. The quest to see them has also brought people together. I delight in the posts about them in my astrophotography groups. While I find all of the "Is it an alien?" misinformation in various publications deeply frustrating, I love that people are looking up.

Going forward into 2026, my wish list is long. Scientifically, I really want a paradigm-shifting dark matter observation. Socially, I want all children to have the food, housing, education and medical care they need in identity-affirming communities. These are big dreams that probably won't happen by the end of the year. But the comets are a reminder that the universe is full of big, wonderful surprises. Just as we do the work of seeking out comets, we should also build the better world we need. ▮

Upending what we know about ancient humans

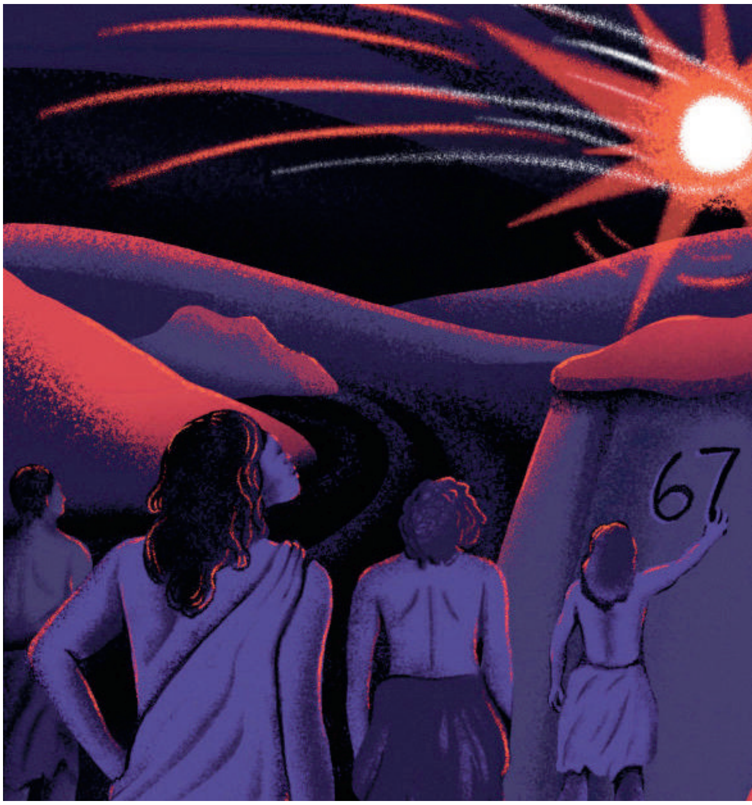
Our Human Story columnist Michael Marshall looks back on the year's major Denisovan discoveries

THIS year marked 15 years since we first learned of the Denisovans, a group of ancient humans that lived in what is now east Asia tens of thousands of years ago. I have been fascinated by them ever since, so this year, I was delighted to see a flurry of exciting findings that expanded our understanding of where they lived and who they were.

The Denisovans were the first hominins to be discovered largely through molecular evidence. The first known fossil was a finger bone from Denisova cave in Siberia, which was too tiny to be identified by its shape, but yielded DNA in 2010. The genetics indicated that the Denisovans were a sister group to the Neanderthals, who lived in Europe and Asia. It also showed that they interbred with modern humans. Today, people in parts of South-East Asia like Papua New Guinea and the Philippines have the highest proportions of Denisovan DNA in their genomes.

Ever since, researchers have been trying to find more examples of Denisovans. It proved to be slow work. Not until 2019 did a second example show up: a jawbone from Baishiya Karst cave in Xiahe on the Tibetan plateau. Over the next five years, a few more fossils were tentatively pegged as Denisovan. They seem to have been big-bodied, with unusually large teeth for such recent hominins.

Then came 2025 and a rush of new finds. In April, we had confirmation of a Denisovan in Taiwan. A jawbone had been dredged from the Penghu Channel in 2008 and was widely suspected



ELAINE KNOX

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to be a Denisovan. Researchers have now confirmed this using proteins preserved inside the fossil. This expanded the Denisovans' known habitats far to the south-east – which makes sense, given where their genetic traces linger today.

Then, in June, came the first Denisovan face (see page 28). A skull from Harbin in north China had been described in 2021 and named as a new species: *Homo longi*. It was large, so again researchers thought it might be Denisovan. Qiaomei Fu and her team extracted proteins from the bone and mitochondrial DNA from the calculus on the teeth. Both indicated that the Harbin skull was a Denisovan.

So far, these findings have all made a lot of sense. The genetics had always indicated that Denisovans roamed widely in Asia, and these fossil finds confirmed that. They also painted a coherent picture of the Denisovans as big-bodied.

However, 2025's other two finds were big surprises. September saw a reconstruction of a squashed skull from Yunxian, China. Yunxian 2 appears to be an early Denisovan, which is a dramatic finding because it is about a million years old. The implication is that Denisovans existed as a separate group at least a million years ago, hundreds of millennia earlier than previously thought. This also indicates that the ancestor they share with us and Neanderthals, known as Ancestor X, must have lived over a million years ago. If this is correct, all three groups have much longer histories than we thought.

"It's a good job I like a mystery, because the enigma of the Denisovans isn't getting solved soon"

Barely a month had passed when geneticists announced the second high-quality Denisovan genome, extracted from a 200,000-year-old tooth in Denisova cave. Crucially, this genome was quite distinct from the first one reported, which was much more recent, and it was also unlike the Denisovan DNA in present-day people.

The implication is there were at least three populations of Denisovans: an early one, a later one and the one that interbred with our species. This third population is, archaeologically, a complete mystery.

Just as we were starting to get a handle on the Denisovans, it turns out their history was far longer than was initially believed and they were also more diverse than we realised. In particular, the Denisovan population that interbred with modern humans remains frustratingly out of reach.

The Denisovans have enthralled me for 15 years because they are so enigmatic, with continent-spanning populations that existed for hundreds of thousands of years, but are known from just a handful of remains. It's a good job I like a mystery, because this one isn't getting solved anytime soon. ▮

We are drowning in a sea of slick, nonsensical AI slop

This Changes Everything columnist Annalee Newitz on how AI-generated content went mainstream in 2025

THERE is no doubt that 2025 will be remembered as the year of slop. A popular term for incorrect, weird and often downright ugly AI-generated content, slop has rotted nearly every platform on the internet. It's rotting our minds, too.

Enough slop has accumulated over the past few years that scientists can now measure its effects on people over time. Researchers at the Massachusetts Institute of Technology found that people using large language models (LLMs) such as those behind ChatGPT to write essays show far less brain activity than those who don't. And then there are the potential ill-effects on our mental health, with reports that certain chatbots are encouraging people to believe in fantasies or conspiracies, as well as urging them to self-harm, and that they may trigger or worsen psychosis.

Deepfakes have also become the norm, making truth online impossible to verify. According to a study by Microsoft, people can only recognise AI-generated videos 62 per cent of the time.

OpenAI's latest app is Sora, a video-sharing platform that is entirely AI-generated – with one exception. The app will scan your face and insert you and other real-life people into the fake scenes it generates. OpenAI founder Sam Altman has made light of the implications by allowing people to make videos featuring him stealing GPUs and singing in a toilet bowl, Skibidi Toilet style.

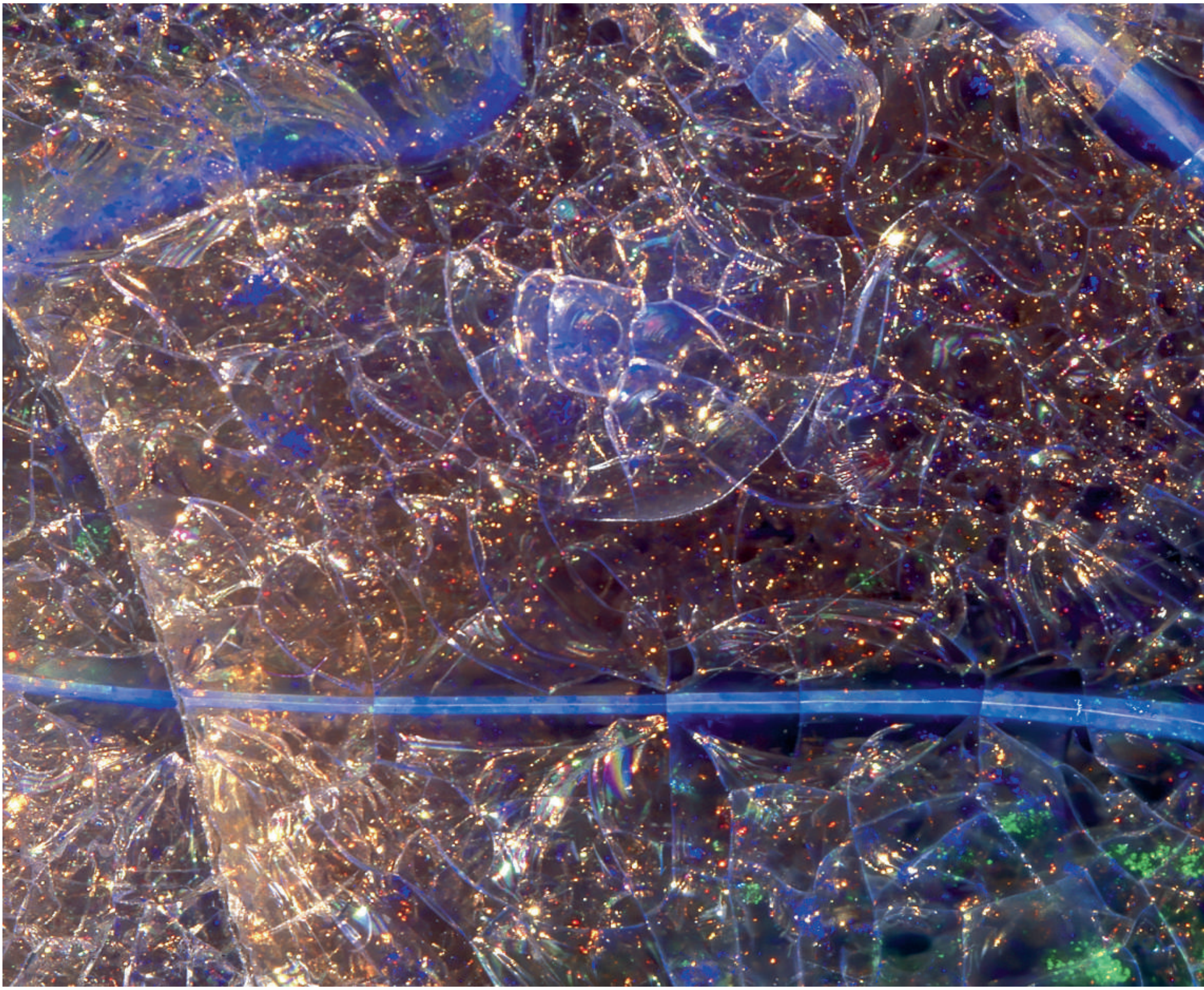
But what about AI's much-touted ability to make us work faster and smarter? According to one study, when AI is introduced into the workplace, it lowers productivity, with 95 per cent of organisations deploying AI saying they are getting no noticeable return on their investments.

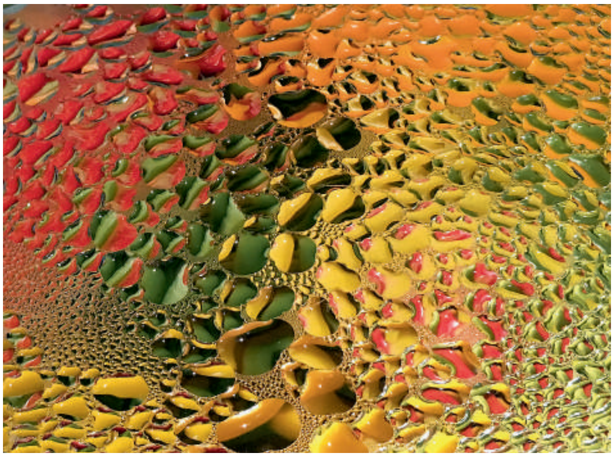
Slop is ruining lives and jobs. And it's ruining our history, too. I write books about archaeology, and I worry about historians looking back at media from this era and hitting the slop layer of our content, slick and full of lies. One of the important reasons we write things down or commit them to video is to leave a record behind of what we were doing at a given period in time. When I write, I hope to create records for the future, so that people 5000 years from now can catch a glimpse of who we were, in all our messiness.

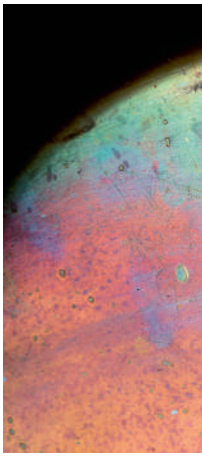
AI chatbots regurgitate words without meaning; they generate content, not memories. From a historical perspective, this is, in some ways, worse than propaganda. At least propaganda is made by people, with a specific purpose. It reveals a lot about our politics and problems. Slop erases us from our own historical record, as it's harder to glean the purpose behind it.

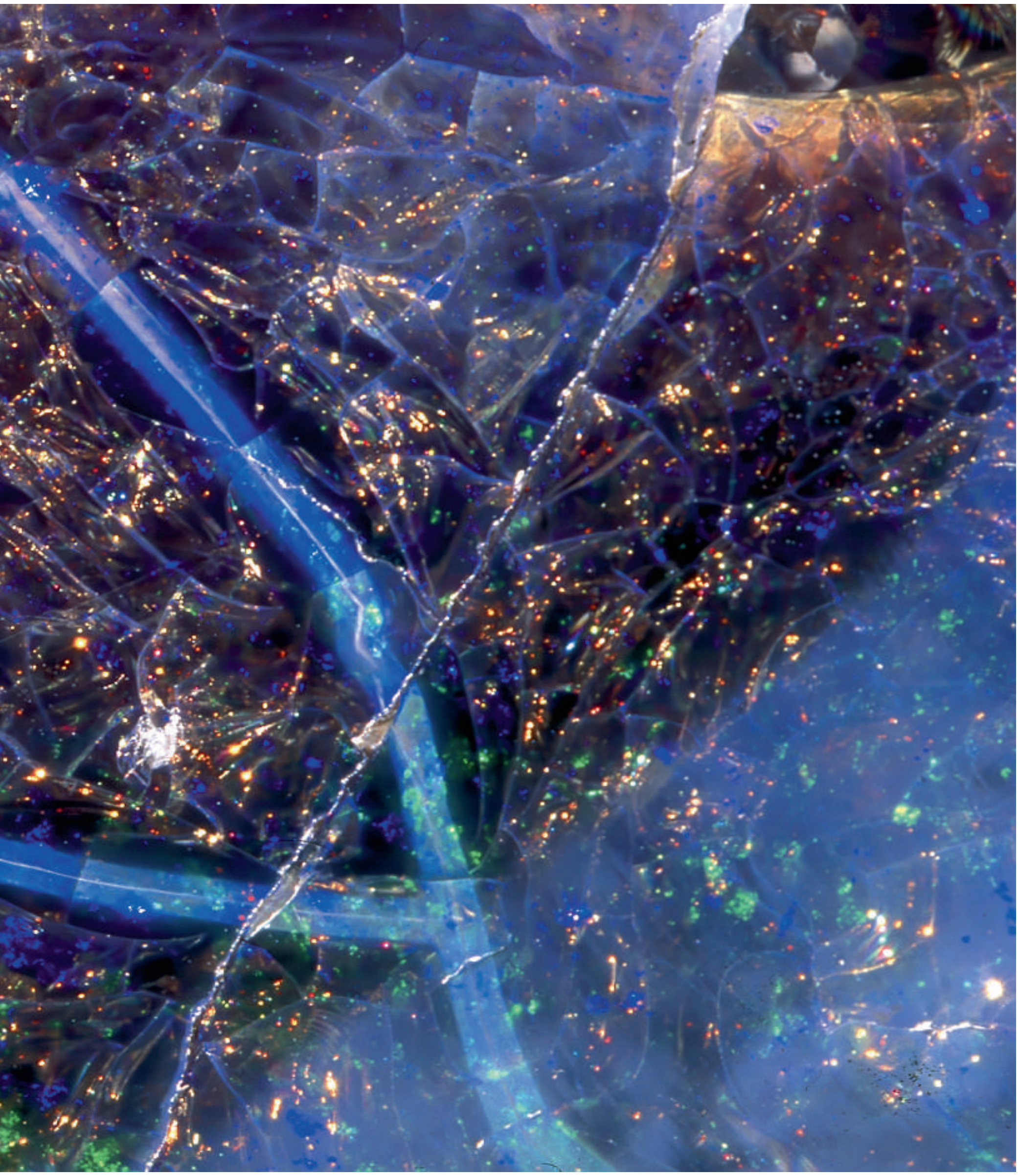
Perhaps the only way to resist the slopification of our culture right now is to create words that have no meaning. That may be one reason why the Gen Z craze for "6-7" has percolated into the mainstream. Even though it isn't a word, 6-7 was declared "word of the year" by Dictionary.com. You can say 6-7 anytime you have no set answer to something – or, especially, for no reason at all. What does the future hold? 6-7. What will AI slop do to art? 6-7. How will we navigate a world where jobs are scarce, violence is on the rise and climate science is being systematically ignored? 6-7.

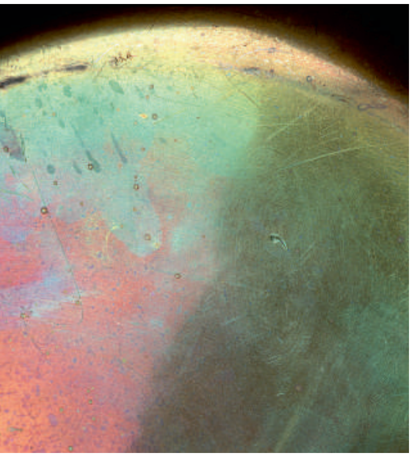
I would love to see AI firms try to turn 6-7 into content. They can't, because humans will always be one step ahead of the slop, generating new forms of nonsense and ambiguity that only another human can truly appreciate. ▮

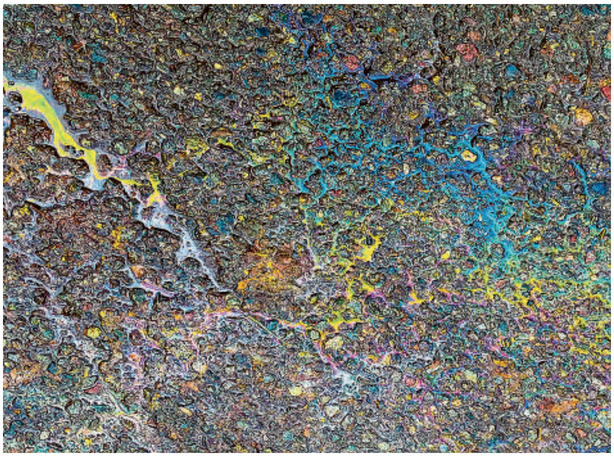












What is it?

Photographer **Felice Frankel**
Candlewick/MiTeenPress

THESE beautiful, enigmatic images were captured by scientist and photographer Felice Frankel in her everyday life. Before you read further, see if you can tell what they depict – we'll reveal all below.

The images appear in Frankel's new book *Phenomenal Moments: Revealing the hidden science around us*. Each close-up, many of which were taken on her phone, comes with an explanation of the scientific processes depicted. "It's like a guessing game," she writes.

So, to the answers… The main image is a piece of opal – the blue lines are veins in the mineral. Light is diffracted as it passes through the stone, and the diameter of the small spheres of silica that make up its layers, plus the spacing between those spheres, determine which colours we see.

The bottom, far-left image was taken when Frankel was sautéing peppers, as condensation formed on the pan lid. These tiny droplets acted like lenses and transmitted the colour of the peppers through the lid and into her camera. To that photo's immediate right is a shot of a 5-centimetre sample of the mineral agate. It was imaged at high resolution by a desktop scanner. The patterns are layers of silica.

Frankel was drawn to the colours in a copper pan in the next image along the bottom row. When copper is exposed to heat and air, it oxidises and forms copper compounds of striking colours. And oil dripping from a car created a thin layer on top of a puddle in the final image. Light reflects from the top and bottom of the oil layer, which varies in thickness. These reflections create wavelengths in varied colours. ▮

Matthew Sparkes

Catching up on the greats

Bored of the festivities? Sick of your relatives? Now's the perfect time to get up to speed with some under-recognised cultural gems, as picked by ***New Scientist***

BILL MCCONKEY

TIME flows ever onwards with reassuring uniformity – at least, that's how it feels to mere mortals unplugged from the weirder parts of physics. But everyone knows that the exception to this rule is the period between Christmas and New Year, in which time behaves strangely, moving like molasses until it lurches forwards as you near your return to normality.

If you usually misspend the twilight days of the year sitting idly in a fog of libations, you might be wondering how to occupy yourself. Fear not: *New Scientist* staff and contributors have crafted a bucket list of all-time cultural greats to fill the long hours of the holiday season. It is an eclectic mix of books, films, television, music, video games and more, designed to highlight some overlooked classics that you simply must try. The only thing they all have in common is their celebration of science, technology, the environment or any other topic you might find in *New Scientist*.

We hope you enjoy our favourites – if you choose to give one a go, your time will pass in the blink of an eye. Bethan Ackerley

Video game

Outer Wilds

Outer Wilds is a rare triumph in video game storytelling. Released in 2019, it broke from a stale formula of largely linear plotlines and choreographed cutscenes in the middle of gameplay, instead opting for narrative experimentation.

You begin as a spacefaring alien in a solar system moments from destruction, stuck in a 22-minute time loop that ends with a supernova. The story is inferred almost entirely through your own detective work, via alien ruins, cryptic logs and astrophysical oddities.

It is also a physics lover's paradise: the game wrestles with quantum entanglement, entropy and non-Euclidean spaces. Its simulation of light bending around black holes is among the most accurate ever rendered in media. The *Echoes of the Eye* expansion adds a second vanished civilisation and feels decidedly more like horror, but it remains true to the game's central design ethos. *Outer Wilds* isn't just a great story in a game, it's a great story only games could tell. **Jacklin Kwan**

Book

Einstein's Dreams

What if there were a place where time literally stood still? This is just one of the possibilities explored in Alan Lightman's book *Einstein's Dreams*, which imagines the visions Albert Einstein might have had while working on his theory of relativity in 1905.

Each beautifully written chapter explores a different transformative scenario and what the ramifications of living in such a world would be. Lightman's focus is on the emotional more than the scientific, resulting in a read that is equal parts moving and thought-provoking. It's a short book, but one that lingers for a very long time. **Michael Dalton**

Film

The Creator

Sci-fi epic *The Creator* is my favourite film of the decade (so far), mixing a utopian view of where human-AI synthesis could take us with a cracking tale of love and redemption. The positioning of the synthesised AI humans as the good guys makes a refreshing and very timely change, and the audiovisuals of a colossal spaceship called the USS Nomad and its frighteningly effective laser alone are stunning. The film's director, Gareth Edwards, also directed *Rogue One: A Star Wars Story*, which shares many of *The Creator*'s hallmarks. Both are well worth watching together this festive season. **Kevin Currie**

Board game

Dobble

ALAMY

If you haven't played *Dobble*, the rules are simple. There are 55 cards, each with eight symbols. Any two cards share one matching symbol. Your goal? Be the first to spot your shared symbol as quickly as possible.

It sounds straightforward, but *Dobble*'s deceptively complex maths and dash of psychology make it my top pick for Christmas gaming. I love how, invariably, every player at some point will insist: "I don't have a match", before finding it and wondering how on Earth the designers ensured that each card pairs perfectly with every other one.

Now, with patronising superiority, you can tell them the trick was to base it on a geometrical pattern called a "finite projective plane", in which any two points create a line and any two lines determine a point. Every point has n+1 lines and every line contains n+1 points. A game of *Dobble* based on the simplest projective

plane would have seven cards and three symbols per card. The full game, with eight per card, creates a more intricate geometric pattern.

Even ignoring the maths, *Dobble* gives your brain a remarkable workout. The varying size and position of the symbols, combined with the speed of play, challenges your short-term memory, visual pattern-spotting networks and executive functioning. Add a jolt of adrenaline and an excitable child or two and you have got a family favourite that is as cognitively rich as it is competitive.
Helen Thomson

Film

Nostalgia for the Light

We humans are unique in our desire to unearth the past, and this drive isn't limited in time. Chilean director Patricio Guzmán artfully and movingly demonstrates this in his 2010 film *Nostalgia for the Light*. It stitches together astronomers looking for the beginnings of the universe in Chile's Atacama desert and the search by a group of Chilean women for the remains of their children, who were disappeared and buried in that same desert during Augusto Pinochet's brutal dictatorship in the 1970s.

These efforts may seem very different, but Guzmán's careful examination makes it clear how important it is not just to understand our past, in all its forms, but to have evidence of it. A line from near the end of the film has always stuck with me: "Those who have a memory are able to live in the fragile present moments. Those who have none don't live anywhere." **Alex Wilkins**

TV show

Halt and Catch Fire

It was called "the best show that nobody watched", and you should do your part to change that. *Halt and Catch Fire* did something I have never seen before or since: it made the early days of tech – not the 2000s post-dot-com bubble that gets so much focus, but the processors being built in Texas in the 1980s – feel as dramatic and consequential as they would turn out to be.

If that sounds boring, hang on. The heart of the series comes from the incredible performances that create the four main characters, half of whom, refreshingly, aren't men. At its core, the show is an exploration of what these antiheroes are willing to put on the line in pursuit of their creative dreams, and the deep connection they find through a shared passion for the technology that would change the world.

Lee Pace and Mackenzie Davis have gone on to give more widely acclaimed performances since, but for my money, neither has reached the emotional heights they did on *Halt and Catch Fire*.
Chelsea Whyte

Podcast

If Books Could Kill

Every couple of weeks, a new episode of *If Books Could Kill* shows up on my podcast player and I set aside an hour to laugh myself half to death. The premise of the show is simple: many popular non-fiction books are terrible, so let's pull them apart and make fun of them.

The hosts are journalist Michael Hobbes and lawyer (until he got fired for his podcasting) Peter Shamshiri. The dynamic between the pair is great: Michael overprepares to the point that his notes are often longer than the book in question, while Peter spends most of his time thinking up the funniest thing he could say at any given moment.

The podcast's targets range from self-help books to those on history and science. Plenty of *New Scientist*-adjacent authors have come under their microscope – notably Steven Pinker, Jonathan Haidt (twice) and Malcolm Gladwell (also twice). You will have read some of these books: you won't believe how flimsy they are.

You have three years' worth of episodes at your disposal, so dive in and prepare to clear the dross from your bookshelves.
Michael Marshall

Film

Babe: Pig in the City

ALAMY

Kids ran crying from the cinema when the highly anticipated sequel to *Babe*, the story of a sheep-herding pig, premiered in 1998. A series of close calls with death, alongside the helplessness of urban living, were too close to the bone even for many parents. But a closer reading reveals *Babe: Pig in the City* to be a moral guide for our times that brims with optimism.

When Babe arrives at the animal hotel in Metropolis in a bid to save his farm, it is ruled as a hierarchy: dogs are bound to one floor, a choir of cats sings on another and Thelonius, an orangutan who cosplays as an aristocrat, watches from above – refusing to believe that a pig can be anything other than meat.

The hotel reflects our troubled relationship with the natural

›

world, in which some branches of the evolutionary tree are valued more than others. Yet Babe's gospel of kindness soon dismantles the pecking order to create what consciousness and feminist scholar Donna Haraway calls a "compost society", which recognises that creatures aren't isolated or unequal, but entangled in a fundamental way.

I have come to see this interspecies philosophy as a kind of mutual aid, which, combined with Babe's desire for self-determination ("I'm not any kind of pie, I'm a pig on a mission"), can only mean one thing: he isn't just a sheep-pig, but an anarchist, too.
Thomas Lewton

TV show

Scavengers Reign

HBO MAX

It can be hard to start a TV show when you know it was prematurely cancelled. That was the sad fate of *Scavengers Reign*, an animated series set on a strange planet called Vesta. But I urge you to give this one a go: it is some of the most breathtaking sci-fi I have seen in years, and it is a beautifully self-contained season.

After the crew of the Demeter 227 are forced to abandon their ship, they crash on Vesta and find themselves surrounded by beautiful, dangerous flora and fauna. These endlessly inventive life forms are a marvel – there are stampeding horse-like creatures with inflating chest sacs, fish that act like gas masks, and a telepathic, parasitic frog called Hollow that extrudes a dark goo. Then there are the humans and Levi, a robot who is really the heart of the show, each of whom reacts differently to the unsettling environment.

If you want to watch some sci-fi that really feels alien, both in its content and its surreal, meditative tone, *Scavengers Reign* is the show for you. **Bethan Ackerley**

Board game

Backgammon

Backgammon is one of the world's oldest board games, with a history stretching back nearly 5000 years. For me, it has the perfect mix of skill and chance. The roll of the dice ensures that anyone can win a single game. A lucky roll can easily turn the tables, allowing a beginner to beat a grandmaster.

This element of luck keeps every match exciting and unpredictable. However, over a series of games, skill will ultimately prevail. Understanding probability and correctly using the doubling cube will pay dividends over time.

Backgammon is a fantastic game that is quick to learn but offers a lifetime of strategic depth. It is also far quicker to play than similar games like chess or Go. The doubling cube makes it perfectly suited for small, friendly wagers, adding an extra layer of excitement to the proceedings if that's your sort of thing. **Martin Davies**

Book

Dark Eden

DARK
EDEN
A NOVEL
CHRIS BECKETT

Chris Beckett's sci-fi novel *Dark Eden* is set on a planet 40,000 light years from Earth, a world with no sun, but where life is thriving regardless – and some of it is human. Almost two centuries earlier, an interstellar spaceship accidentally ended up nearby. Two astronauts were left behind while the others went for help. It never came, and now the world is peopled with the astronauts' descendants, who eat the weird animal life found there and live under "trees" that tap into the planet's geothermal heat.

Their language and culture have also developed in unexpected ways. Inbreeding and a lack of nutrients mean they are small and plagued with recessive genes, but they are surviving while they wait for the "Landing Veekle" they have been promised will save them. Winner of the Arthur C. Clarke award in 2013, *Dark Eden* remains one of my favourite pieces of sci-fi: strange and marvellous, uncomfortable and thought-provoking. **Alison Flood**

Video game

Horizon Zero Dawn

Long periods go by when I never touch a controller, but every now and then, a game comes along that completely enthrals me. My all-time favourite is *Horizon Zero Dawn*, a vast, open-world game featuring robotic dinosaurs. It sounds ridiculous, but there's a strong story involving the origins of the central character, Aloy, with some emotional moments along the way. No spoilers, but AI features heavily.

The reclaimed-by-wilderness landscape is gorgeous, too. The graphics were amazing for 2017, when the game first came out, and got even better with the release of a remastered version last year. While much of the gameplay revolves around fighting the robotic animals – it will make sense, trust me – it's not just about button-mashing. The key to combat is exploiting weaknesses and taking advantage of features in the environment. There is a 2022 sequel, *Horizon Forbidden West*, that improves on the original in just about every way, but I would recommend you start at the beginning. **Michael Le Page**

Book

Under the Sea Wind

Rachel Carson, one of the most important figures of the 20th century, is primarily known for her fourth and final book, *Silent Spring*. Its spectacular and deserved success obscures her earlier work, making us forget she was a marine biologist before she was an ecological campaigner. Her first three books were about the ocean and the shore. *Under the Sea Wind*, her first, was published in 1941, and takes the point of view of a sanderling, a mackerel and an eel.

The book tells the life stories of these animals, and though inevitably a work of imagination, it is also one of great perception and beauty. Carson was in tune with the ebb and flow of tides and the interconnectedness of marine

food webs. She knew that life was networked and dynamic. Before her, environmentalism was broad brush, lofty and colonial; it was all about wildernesses. Carson showed us how to think ecologically, how to love life in all its complexity. **Rowan Hooper**

TV show

Mystery Science Theater 3000

ALAMY

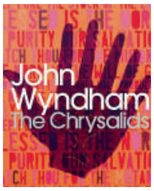
Some films are so ridiculously awful that the only thing you can do is make fun of them. Enter *Mystery Science Theater 3000* (*MST3K*, to its friends). The premise of this cult TV series is that a worker grunt on a spaceship is forced to watch bad – and I mean, bad – retro sci-fi movies (think monster costumes with visible zippers and flying saucers made of hubcaps) to see how long it takes him to snap. Rather than break under torture, he watches the films with a pair of sassy companion robots he has built, and the trio shout rapid-fire one-liners at whatever terrible movie they are watching.

MST3K holds a special place in my heart because I used to watch it with my dad as a kid. It's impossible to pick a favourite episode, but for the holiday season, "Santa Claus Conquers the Martians" (pictured) – named after the real film it features – is a sure bet. Episodes can be hard to find online, but try Gizmoplex or Amazon Prime Video. **Kelsey Hayes**

IF BOOKS COULD KILL
KRAFTWERK
COMPUTER WORLD

Book

The Chrysalids



The Chrysalids, first published in 1955, is set in a post-nuclear-war future in which any genetic flaws are branded "blasphemies" and are ruthlessly stamped down on. When our hero, David Strorm, makes friends with Sophie, a little girl with six toes on one foot, you know it can only be a matter of time before something bad happens.

In fact, it's not just Sophie who has a secret to hide. David and some other children in the community of Waknuk are themselves hiding quite a big mutation: they are telepaths. Eventually, they are forced to flee. Can they reach "Sealand", a distant realm where they might be accepted for who they are?

This is very unlike John Wyndham's other books: less stiff, more human and exciting. I think it's his best book by far. I grew up on it, reading it over and over, and its hugely original story and powerful imagery have never faded from my mind. **Emily H. Wilson**

Music

Computer World

Business. Numbers. Money. People. Not much has changed since 1981. At least, that's what I think every time I hear the opening track of *Computer World*. Created by Kraftwerk, the pioneers of electronic music, this album is deliciously nerdy. It feels like respawning into an old-school video game, laser guns and all. You can almost hear the pixels.

That isn't to say it is unpolished or archaic. If anything, its production beats that of most modern electronic albums. And there is no fluff. Each beep, boop and bop in the 34-minute runtime feels essential. What I appreciate about *Computer World* – and Kraftwerk more generally – is that it somehow celebrates the burgeoning digital world while critiquing it too. Between a dorky anthem to the pocket calculator and an apt depiction of a lonely night in front of the TV, this album is both retro and relevant to today. **Grace Wade**

Film

Stalker

SHUTTERSTOCK

The 1979 film *Stalker*, directed by Andrei Tarkovsky, is a grey fever dream full of dystopian landscapes and existential questions. Two archetypal characters, a writer and a professor, follow a mysterious guide through a ravaged land into a special room that, supposedly, will turn their innermost desires into reality.

The film is over 2 hours long, but so immersive that it might as well last for centuries. Its core themes of desire, faith and how to live a good life feel equally timeless. *Stalker* draws on everything from Dante's *Inferno* to Soviet science fiction and ultimately lands on something like a fairy tale gone wrong, except it offers no easy morals – just an awful lot of contemplation that is much richer than its post-apocalyptic yet minimalistic visuals. It's a film that will stay with you even if you have never felt lost in the wilderness. **Karmela Padavic-Callaghan** ■

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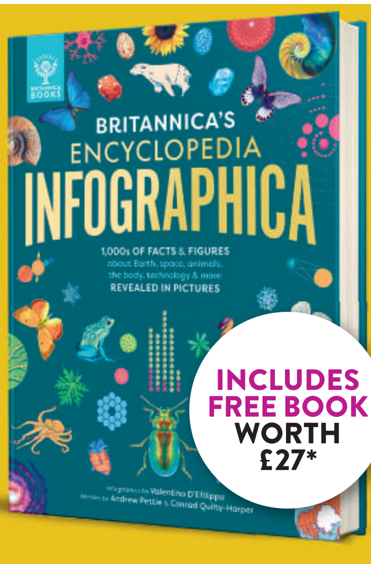
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Editor's pick

Making sense of quantum cause and effect

29 November, p 36

From Alistair Fraser, Whanganui, New Zealand

As an ordinary reader trying to make sense of the universe before breakfast, I was delighted by your feature on quantum causality. The idea of "causal bubbles" gave me a way to picture the quantum world without feeling out of my depth.

By chance, I had just finished your article on the ancient origins of sperm (29 November, p 11). It struck me that these two stories – one probing the deepest structure of reality, the other tracing the machinery that eventually produced all of us – sit together beautifully: the same quantum rules shaping electrons also shape the proteins powering our earliest ancestors. For once, physics and biology felt like they belonged to one big cosmic *whakapapa* (lineage).

From Chris Arnold, Perth, Western Australia

The article on causality in quantum theory reminds us that, until an observer takes a measurement, we are confronted by a fog of possible alternatives and that the measurement will cause these distributions to "collapse" to finally reveal definite properties.

These quantum scenarios appear less weird if we liken them to every point in space constituting, first, a set of actual properties – being a consequence of all past events – and, second, a cloud of future possibilities. As the future transitions across the present boundary to become the past, space and time act as filters to determine which future possibilities emerge from the fog.

Our observer's measurement is a mere snapshot, captured from the continuous stream in which future possibilities transition to past certainties. All the while, the effects of ensuing events feed back into and update future distributions. Under this scenario, measurements will potentially contribute to the continuously updating distributions, but won't cause them to collapse.

From Rod Newbery, Cambridge, UK

Your feature explores the issue that nothing seems to be fixed until it is measured. Measurement can be an observation. What quantum theory doesn't explain is that it all depends on who is observing an object. That is why, after I have failed to find a particular object in the fridge, when my wife then opens the door, there it is, right at the front.

Why oversized cars are a massive problem

22 November, p 19

From Wai Wong, Melbourne, Australia

I cannot agree more with Anthony Laverty's article on the need to curb the trend towards big cars. Not only are they more lethal in a crash, they are also more likely to be involved in accidents because of larger blind spots and longer braking distances. I call for regulations to inconvenience big car owners in subtle ways.

In the environmentally friendly Albury-Wodonga region in Australia, along the border between Victoria and New South Wales, both councils have done something in this vein: many free public car-parking spaces are too small for large cars and their owners are supposed to park further from facilities.

From Karen Morant, London, UK

Laverty perfectly sums up what can only be described as the biggest environmental crisis ever to hit UK roads, and beyond. Let's hope this subject gathers much-needed momentum.

Sometimes the old ways might be the best

27 September, p 23

From Mark Oliver, Melbourne, Australia

In reference to Claudia Canavan's article, "Time for a new you", I have been applying the Myers-Briggs Type Indicator – which categorises people into 16 personality types – for over 30 years.

Despite often being dismissed, it has always "said" everyone is both an extrovert and introvert (just not equally so), and that we not only change our personality, but also do so in predictable ways depending on which personality style we start with. Sometimes, science is best applied by looking at the older models with a better eye than looking for new ones.

A hunch about human consciousness

25 October, p 36

From Ben Hespe, Manchester, UK

As an agnostic on such matters, but a fellow subscriber to Robert Lawrence Kuhn's hunch that the ultimate nature of consciousness is the key data point to understand humanity's existence – be it physical and accidental or something more profound – I found it disheartening that the previous letters published about his feature uniformly exhibited an insistence that the materialist game is the only one in town, or even that the whole field of study should just be abandoned!

Perhaps we should consider the end of his published paper on the landscape of consciousness, where he states: "Me, I just don't know … My own hunch, right here, right now—if I'm coerced to disclose it and for what little it's worth—might be something of a Dualism-Idealism mashup. (I can describe; I dare not defend.)"

It seems that plants don't love rock and roll

22 November, p 43

From Craig Morris, Pietermaritzburg, South Africa

James Wong examined the evidence that playing music benefits plants and notes that, while plants cannot hear, they can respond to vibrations, although which types of music and sound affect them positively or negatively remain unknown.

A 2018 study in *Ecology and Evolution* addressed this by testing the music group AC/DC's claim that "rock and roll ain't noise pollution" using soybean plants, aphids and ladybirds. Exposure to rock music and urban noise reduced ladybird predation, leading to higher aphid densities and, through weakened trophic cascades, lower plant biomass, demonstrating that certain loud sounds can disrupt predator-prey-plant interactions and, ultimately, contradicting AC/DC's claim that rock and roll is harmless to plants.

Science is finally catching up with philosophy

15 November, p 28

From Mark Dunn, Oxford, UK

Your article on giving up on your ambitions put me in mind of a passage from P. G. Wodehouse that has stayed with me since I read it over 30 years ago. In it, he succinctly summarises the gist of the article: "'Well, well,' he said, 'if I cannot compel circumstances to my will, I can at least adapt my will to circumstances. I decide to remain here.' Which he did, and had a not unpleasant time." It looks like science is finally catching up with the great philosopher!

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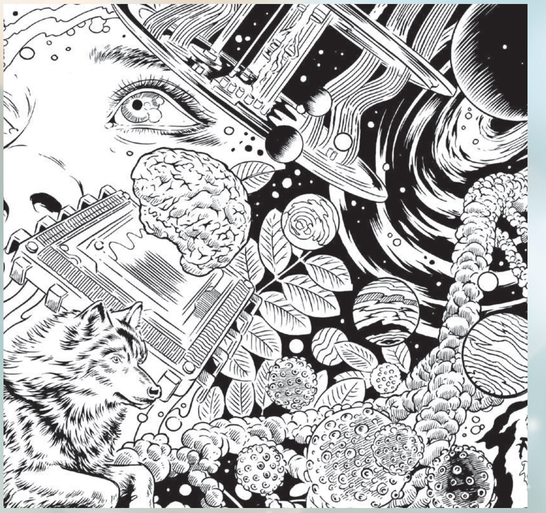

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Sharpen your pencils and look back at some of the science stories that hit the headlines in 2025

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ALENA IAGUPA/GETTY IMAGES

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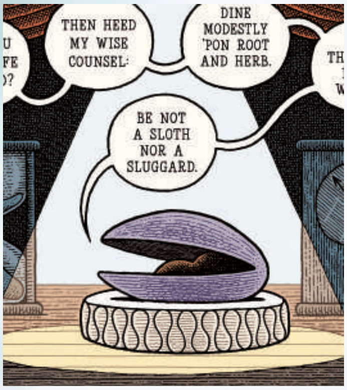
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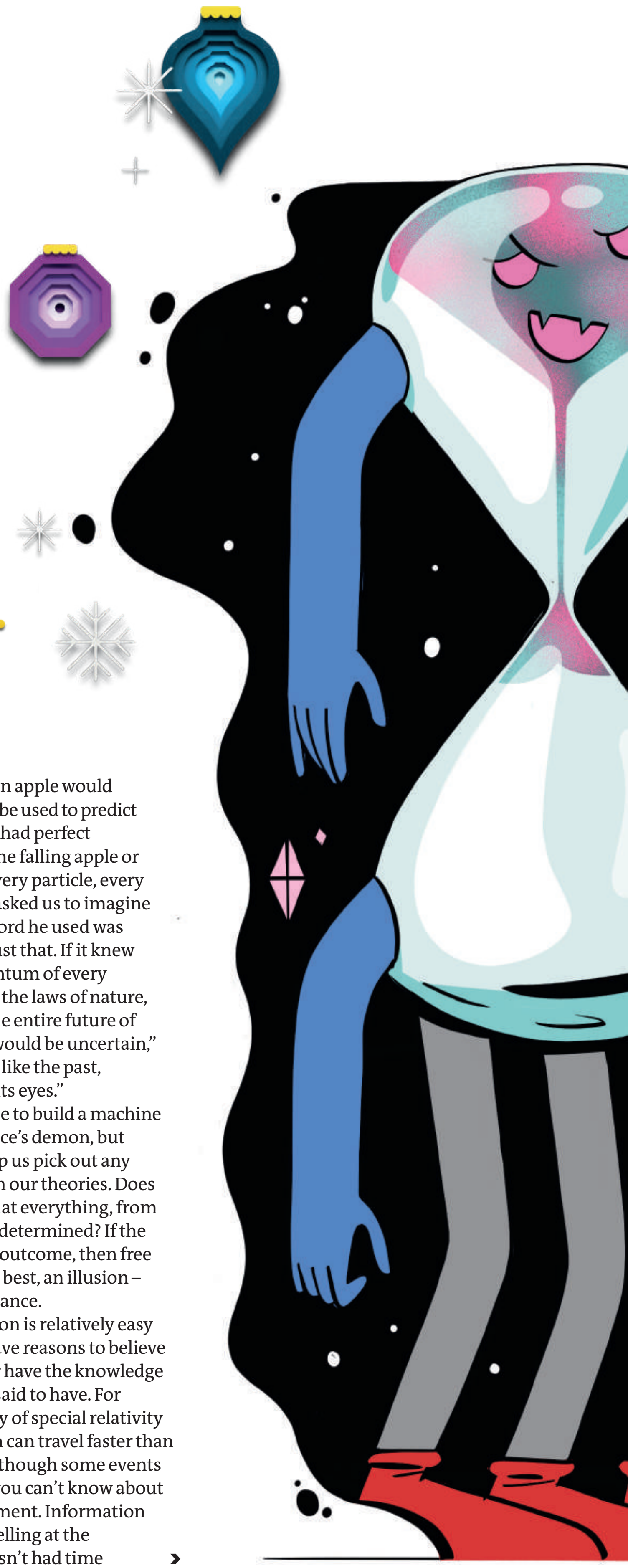
TIM MCDONAGH

Slaying physics demons

Three "demons" have haunted physicists for centuries, and vanquishing them hasn't been easy, finds **Dan Falk**



THERE is a long history of doing physics by imagination. Albert Einstein built his special theory of relativity after imagining himself chasing a beam of light. Erwin Schrödinger gave us a cat that was both alive and dead. Mathematician David Hilbert demonstrated the counterintuitiveness of infinity by imagining a hotel with an infinite number of rooms and guests. By taking creative liberties, physicists use thought experiments to stress-test ideas and so better understand them.

Curiously, three of the most enduring and perplexing thought experiments all involve what have come to be known as "demons". The most famous is Maxwell's demon, devised in 1867, which imagines a tiny being with strange but logical powers. Along with two other similar thought experiments – Laplace's demon and Loschmidt's demon – it still gets physicists scratching their heads today. Thinking about these demons, it turns out, can help us come to grips with some of the trickiest concepts in physics.

"The exciting and amazing thing is that scientists are able to learn so much about reality by going into these fictional spaces," says Michael Stuart, a philosopher of science at the University of York, UK. "And many would argue that science would be impossible without it."

The person who conjured up our first demon was a polymath working in the long shadow of Isaac Newton. In 1814, Pierre-Simon Laplace asked a simple question: if Newton's laws could predict how an apple would fall, could the same logic be used to predict everything? What if you had perfect knowledge, not just of one falling apple or orbiting planet, but of every particle, every object, everywhere? He asked us to imagine a demon – though the word he used was "intellect" – capable of just that. If it knew the position and momentum of every particle and understood the laws of nature, then it could calculate the entire future of the universe. "Nothing would be uncertain," he said. "The future, just like the past, could be present before its eyes."

We might never be able to build a machine with the powers of Laplace's demon, but imagining it can still help us pick out any logical inconsistencies in our theories. Does science actually mean that everything, from planets to people, is pre-determined? If the laws of physics fix every outcome, then free will would seem to be, at best, an illusion – a byproduct of our ignorance.

Happily, our first demon is relatively easy to exorcise. Physicists have reasons to believe that no entity could ever have the knowledge that Laplace's demon is said to have. For starters, Einstein's theory of special relativity says that no information can travel faster than light. That means that although some events may affect your future, you can't know about them in the present moment. Information about those events, travelling at the speed of light, simply hasn't had time

›

ANTONIO SORTINO

to reach you, which defeats Laplace's demon.

And even if the demon could access information from all edges of the universe, quantum mechanics throws up another hurdle. Since the 1920s, we have known that there is no way of being certain of a particle's position and its momentum at the same time, so the demon simply cannot know exactly where each particle is and what it is doing. It could describe only the probabilities of a particle's properties.

Laplace's neat particle-by-particle picture of reality is replaced by a quantum universe described by a vast, shifting wave function, an abstract mathematical object that encapsulates all the outcomes that could potentially happen. Even if a demon could keep track of all these outcomes, it wouldn't know which one would eventually become real.

Turning the clock back

Laplace's demon seems to lose its teeth, then, but there were more devilish thought experiments lying ahead. Our second demon cropped up at the height of industrialisation. Steam engines had given new urgency to questions about heat, energy and disorder. Physicist Ludwig Boltzmann tried to explain entropy, a slippery concept that captures how systems tend to grow more disordered over time. Sandcastles disintegrate, ice melts, rust forms, and so on. Boltzmann believed he could explain it by zooming in on reality and looking at the tiny building blocks of big systems, like individual molecules of gas filling an entire room.

But his older colleague, physicist Josef Loschmidt, had doubts about this approach and posed a simple but devastating challenge in 1876. Imagine the universe frozen in time. Every molecule has a position and direction of motion. Now, Loschmidt said, reverse the direction in which each particle is travelling. Loschmidt's original formulation didn't involve a "demon," but later versions often add one that can somehow see and freeze all the particles – mostly because of what came later.

Loschmidt's scenario troubled physicists so much because it seems to present a time-related paradox. At the level of particles, nothing seems to be particularly wrong when the directions are reversed – no laws of physics are broken. But zoom out and the macroscale effects would be unthinkable: puddles would freeze into perfect ice cubes and broken mugs would reassemble themselves as the world starts playing backwards. It prompts us to ask: if we can reverse time trivially in the micro-world, why does it only ever seem to run one way for us?

Later experiments would try to reverse time, just like Loschmidt's demon. In the 1950s, Erwin Hahn used radio waves to briefly nudge electric dipoles (such as the hydrogen atoms in a water molecule) into spinning in unison, temporarily lowering the system's entropy. This made it look as if time were running backwards. So, was Loschmidt's demon capable of defeating the concept of entropy?

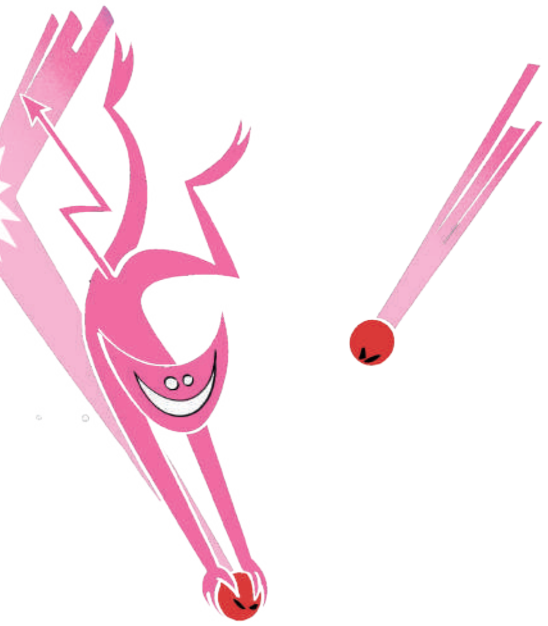
Not quite. We now understand that entropy doesn't mean that systems must always slide into chaos. Some systems can even evolve to be more ordered very briefly. But entropy does conquer all eventually, as Hahn saw. Once he switched his radio beam off, the dipoles fell back into disorder.

So, why does entropy always increase? From what we can tell, the cosmos started in an extraordinarily tidy state: low entropy, with all the pieces neatly arranged. That gave it only one way to go – towards messiness. There are just many more ways to ruin a neat system than to make it even more ordered, making disorder more likely. This means that Loschmidt's demon can, in theory, reverse the trajectory of tiny particles, but it is doing so against the odds.

"The status of the second law isn't like Newton's second law," says philosopher Katie Robertson at the University of Stirling, UK. "It's got this probabilistic nature, like 'you probably won't manage to reduce entropy'."

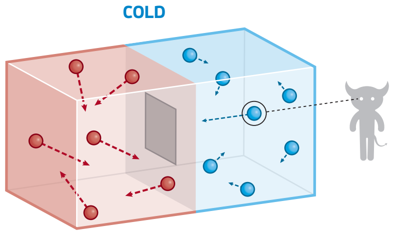
Ultimately, then, the laws of probability exorcised this demon, but not before it helped us deepen our understanding. Boltzmann, in response to Loschmidt, abandoned his original approach and adopted one based on statistics because it better captured this soft logic of probability. His refined thinking led to the Boltzmann equation, which is now carved on his tombstone.

The third and most famous demon came in 1867, less than a decade before Loschmidt raised his challenge, from physicist James Clerk Maxwell. Like Loschmidt, he was interested in the second law of thermodynamics, but he attacked the idea that entropy always increases from a different angle. Instead of rewinding the universe, what if you could interfere with it, molecule by molecule? Picture a meddling being – which was later described as a demon by physicists like William Thomson – that could push around gas molecules trapped

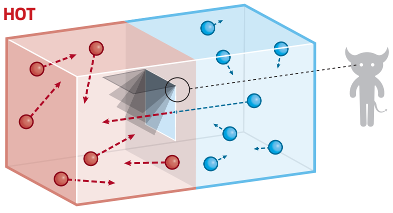


Doing work at no cost?

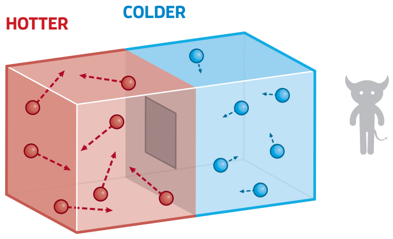
Maxwell's demon is a thought experiment where an entity knows the positions and velocities of particles in a box. Using its knowledge, it sorts fast-moving particles from slower ones, creating a larger temperature difference.



Imagine particles in a box with two compartments – one slightly hotter than the other – separated by a trapdoor. A demon knows the velocities of all particles in the box.



If there is a frictionless door connecting the boxes, the demon can open it to allow the fast molecules from the cold box into the hot box.



The hot box gets hotter without the demon doing any work, which seems to violate the laws of thermodynamics.

EN of WANDS
E of SWORDS
THE HANGED ONE
N of PENTA
TWO

BILL O'LEARY/THE WASHINGTON POST VIA GETTY IMAGES

Laplace's demon could calculate the future of the universe

in a box, partitioned by a trap door. Over time, it could separate fast-moving molecules from slow ones, violating the second law (see "Doing work at no cost?", left).

Solving the paradox

Various simple "solutions" spring to mind. Perhaps the demon has to exert energy to open and close the door. But, in principle, this "work" could be arbitrarily small. The demon could be as light-fingered as you like, and the paradox would remain.

Instead, physicists began to suspect the true cost wasn't in the energy the demon expends, but in how much information it would have to process. Keeping a tally of each molecule's position and momentum would seem to require a memory of some sort. And it turns out, this memory isn't free.

In the 1920s, physicist Leo Szilard showed that even in a stripped-down version of Maxwell's setup, with just one molecule bouncing around inside the box, a clever demon could still extract work from the system. But to do so, it would need to observe the molecule and store that information, which he argued would require energy.

Eventually, something gives. In the 1960s, IBM physicist Rolf Landauer made the crucial point: for the demon to keep functioning, it must clear space in its memory, and that process generates heat, raising the entropy of the system. The second law is saved.

However, physicists made a crucial realisation at the same time: information was a physical resource, just like energy. Knowing something about a system isn't just a matter of abstract bookkeeping. Under the right conditions, information can even be treated as fuel. After all, Maxwell's demon somehow converts information into work. Today, the demon is a mascot for machines that operate where information and energy intertwine. These "information engines" don't just challenge our intuitions – they promise to turn the demon's logic into working technology. In 2024, researchers built a quantum version of Szilard's engine to charge batteries inside a quantum computer. Instead of a demon, researchers used microwave pulses to corral more energetic qubits away from less energetic ones, creating an energy differential that can do work, like a battery.

"Maxwell's demon hasn't been exorcised at all. It's been reborn"

They are still far from powering your phone, but the hope is that these new tiny quantum engines can help move particles or flip qubits using information.

Seen this way, Maxwell's demon hasn't been exorcised at all. It's been reborn in ways Maxwell could have never imagined – not as a threat to the second law, but as a guide to the strange and subtle ways nature permits us to exploit information as a physical resource.

Together, these demons have tested the limits of theory and intuition. While a few have been kept at bay, new paradoxes creep in. But these are demons that physicists don't really mind. These devilish thought experiments are a beloved way that scientists push the envelope of what they know. ▮

Dan Falk is a demon at Christmas card games

The oldest beer

Did our ancestors start farming so they could drink more alcohol? **Michael Marshall** investigates

KORON/GETTY IMAGES

WHATEVER you're tucking into this festive season, chances are you didn't have to kill it yourself or forage it from the wild. For that, you can thank your ancestors who, starting around 10,000 years ago, pulled off one of humanity's most dramatic transformations: they began shifting from their traditional lifestyle of hunting and gathering to become farmers.

Why this happened is puzzling, given that our species had survived successfully for around 300,000 years without having to reap and sow – not to mention milk, shear and shepherd.

Many ideas have been put forward as possible explanations. Maybe farming offered a more reliable source of food. Maybe it allowed people to be less dependent on their neighbours. Maybe it was about wanting to stay in the same place, perhaps because a particular location had religious significance or loved ones were buried there.

Or was it more about getting wrecked with your mates? That might sound laughable, but then, as now, alcohol would have gone beyond being a source of pleasure (hangovers notwithstanding) and provided a means of social bonding. We know networking has been central to human success, and if you want to lubricate these relationships regularly with beer or other alcoholic beverages, you need a reliable supply of cereals. So, did our ancestors upend their lives for a tipple?

Anthropologists have been pondering this possibility since the 1950s. However, they didn't have the technology back then to test the idea. The challenge is to distinguish between beer and bread, which is considered by many to be a more likely candidate for driving the rise of farming.

Baking bread and brewing beer look superficially similar in the archaeological record, says Jiajing Wang at Dartmouth College in New Hampshire. Both involve grinding up cereals and mixing them with water, leaving starchy residues. Researchers needed a way to distinguish beer starch from bread starch. They also needed to be able to tell which was older.

As a result, a handful of archaeologists, including Wang, have spent years on what may seem like a quixotic effort: to find evidence of the oldest alcoholic brew.

A good starting point was the later settled societies, like ancient Egypt, where beer-making was glaringly apparent. Egyptian archaeological sites often contain distinctive pottery jars. "They literally just call it a 'beer jar'," says Wang, because its shape resembles a fermentation tank.

In the past few years, she and her colleagues have confirmed that these were used to brew and store alcohol by identifying telltale microscopic remains preserved inside. At Hierakonpolis in southern Egypt, for example, they found beer jar fragments containing starch granules from cereals, yeast cells and crystals of calcium oxalate, or "beer stone". These showed that people there were making beer from a mixture of wheat, barley and grass between 5800 and 5600 years ago – more than 2000 years before the first pharaoh of a unified Egypt.

Prehistoric brewing

"Those people were making beer at a quite industrial level," says Wang. These early beverages weren't like modern ales or lagers, though. "They sprouted the grains, and they cooked them, and then they used wild yeast to convert some of the sugary stuff into alcohol," she says. The result wasn't a clear liquid, but a "sweet, slightly fermented porridge".

Such findings have provided a blueprint for the kind of evidence that can demonstrate prehistoric beer-making. The next challenge was to see just how far back in time such evidence could be found.

In 2016, Li Liu at Stanford University in California, Wang and their colleagues described a site called Mijiaya in northern China, where pottery vessels revealed traces of beer brewing 5000 years ago. The Mijiaya people used an unusual mix of plants for their beer: broomcorn millet, another kind of millet called Job's tears, barley and tubers.

Five years later, Wang and Liu described similarly ancient evidence of boozing at the Xipo site near the city of Xi'an in northern China, which contains artefacts from a culture called Yangshao. Rice and millet were fermented in large vats using a red mould called *Monascus*, which is still used to make fermented foods such as rice wine, as part of a starter called *qu*. They suggested that elite people consumed the beer during "competitive feasts".

The oldest evidence, however, is from the Shangshan culture on the lower Yangtze river in southern China. Discovered by Liu and her colleagues two decades ago, it is one of the earliest farming societies, dating from between about 10,000 and 8500 years ago. In 2021, a team led by Wang described a Shangshan site called Qiaotou, which is between 8700 and 9000 years old. It is a mounded platform several metres high, surrounded by a ditch. There are no houses on the mound. Instead, it is dotted with burials, accompanied by painted red pottery.

The Shangshan people were "wonderful, highly skilled pot-makers", says Wang. On the pottery, the team found traces of rice, Job's tears and unidentified tuber-like growths used to brew beer. The rice beer may have been consumed during funeral feasts or buried with the dead, she says.

Then, a year ago, Liu and her colleagues described the oldest evidence of brewing in East Asia to date. Her team had examined 12 pottery sherds from the deepest layer of the original Shangshan site, which is between 9000 and 10,000 years old. "This represents the earliest phase of Shangshan culture," she says. The sherds carried traces of rice, other cereals like Job's tears, acorns and lilies – and the remains of a *qu* starter that contained *Monascus* and yeast.

At this time, "domestication was already ongoing", says Liu, and clearly so was beer-making. This is all compatible with beer being a major driver of domestication. "There's a surplus of alcohol production because you have a cereal surplus," she says.

Traces of rice beer were found in this pot from a 9000-year-old burial site in Qiaotou, China

JIAJING WANG ET AL. (2025)

> **"Early beers were like a sweet, slightly fermented porridge"**

Compatible, but not proof, unfortunately. Because it turns out that the oldest bread long predates the Shangshan beer – and, indeed, the advent of farming. At Shubayqa 1 in Jordan, archaeologists have found evidence of "bread like products" from between 11,600 and 14,600 years ago. The people who made this early bread were Natufians, who are known to have often settled down in one location for extended periods of time. Nevertheless, they got almost all their food by hunting and gathering.

To complicate things further, it turns out that these hunter-gatherers also appear to have brewed beer. Raqefet cave in Israel was a Natufian burial site, where about 30 bodies were interred. There, Liu, Wang and their colleagues found three stone mortars that had been packed with multiple wild plants, including wheat, barley and legumes, and then left to ferment, producing a porridge-like beer. The vessels dated from between 11,700 and 13,700 years ago – evidence that brewing also predates farming.

The question of whether beer or bread came first remains unresolved. "We still don't have hard evidence to answer that," says Liu. It is similarly unclear whether beer or bread – or something else – was the main motivation for the farming revolution that would eventually provide the food and drink on your festive table.

"I wouldn't be surprised if both were the motivations," says Wang. After all, history is never simple: why would prehistory be any different? ▮

Michael Marshall enjoys a brew or two

Aged like fine clams

What tips about living longer can we glean from the world's oldest animal, asks **Rowan Hooper**

I WAS wondering, as I began working on this story, whether to eat my subject as part of the research. I imagined a bold opening: "This is the longest-lived animal in the world – and it tastes great."

Since the animal in question is a species of clam, I visualised a spaghetti alle vongole with plenty of garlic. But setting aside the ethics of killing and eating a fellow animal, and the ecological damage we are doing in over-exploiting the ocean, I realised there is another consideration. This animal – the ocean quahog, *Arctica islandica* – can live for at least 500 years. Killing it just seems wrong. So, no, I won't eat this mollusc. Let me amend my introduction: this is the longest-lived animal in the world – and my mission is to discover its secret.

You can be forgiven if you haven't heard of the ocean quahog, also known as the Icelandic cyprine: it isn't the sort of animal that gets much TV time. It is a large bivalve mollusc that lives buried in the sand on both coasts of the Atlantic, from the southern warmth of Florida and Cadiz in Spain, to the colder waters of Quebec in Canada and Norway. If you have had clam chowder in the US, you will have almost certainly eaten it. Its shell is fine-lined like the rings of a tree trunk, and like tree rings, you can count these lines to tell its age.

The oldest known specimen was called Hafrún by researchers, an Icelandic name that means "mystery of the ocean". Hafrún was born in 1499 and lived as its ancestors had done for generations, quietly on a modest diet gathered off the coast of Iceland. In that sense, its life was unremarkable, but for the fact that it went on and on – and on. It ended, in fact, only in 2006, when it was dredged from the sea by a team from the University of Exeter, UK. Paul Butler was the researcher tasked with ageing it.

"Its age was initially published as just over 400 years, but closer reading of the growth lines and comparison with other shells showed it was in fact 507 years old," he says. It is likely there are older ones still out there, especially in the cold waters around Iceland, where they seem to grow more slowly and live even longer. Is there an upper limit to their age? "It's hard to believe they live a lot longer," says Butler, "although we did once get the ages of a few individuals analysed by a mathematician who said in principle they could live forever." Well, that's mathematicians for you.

The key to the quahog's longevity appears to be in its mitochondria – the structures in our cells that use food to provide us with energy. By "us", I mean us eukaryotes – all complex organisms, from yew trees to jellyfish and rabbits. "Having robust mitochondria, which *Arctica islandica* has is paramount for healthy ageing in a wide variety of model species," says Enrique Rodriguez, who researches mitochondria at University College London.

Tough as old clams

Quahog mitochondria are, quite literally, tougher. They have a membrane more resistant to damage than those in other species. The membrane of a mitochondrion is packed with protein machinery that processes electrons and protons and generates ATP, the universal molecule of energy used in cells. In quahogs, this machinery is bigger and more bundled together, which makes it more robust. "The proteins are higher-molecular-weight, more complex structures," says Rodriguez. "They are more joined together."

DGDIMAGES/ALAMY

The ocean quahog is normally found buried in the sand

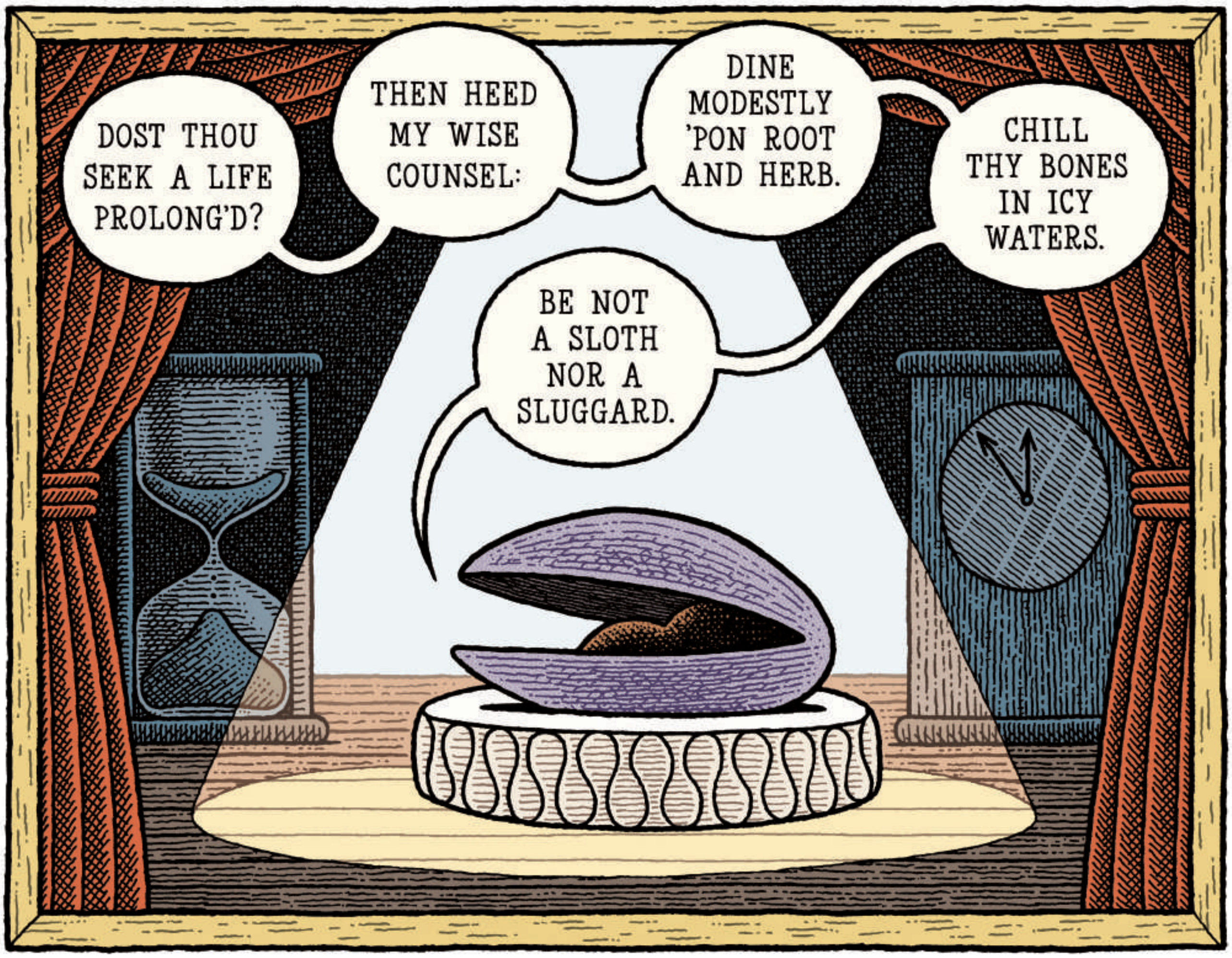
Thanks to this machinery, quahogs experience less damage to their mitochondria. This is partly because they are more careful at marshalling the billions of protons and electrons criss-crossing these membranes every second. When electrons leak, they produce reactive oxygen species (ROS) such as hydrogen peroxide, which cause damage. Rodriguez likens it to cars in traffic. In normal mitochondria, a red light causes cars to back up, their exhaust spewing out and damaging the environment. In quahog mitochondria, however, the traffic light – in this case, a protein complex – is far more efficient at moving traffic, and less exhaust billows out.

But it isn't just the robust membrane that helps a quahog have a healthy lifespan. It is also because quahogs mop up the ROS that do leak out. To use Rodriguez's analogy, this would be like cleaning up car exhaust fumes.

Rodriguez compared the antioxidant capacity of the quahog with a range of shorter-lived related species and found it has three to 14 times the ability to mop up ROS. All this adds support for what is known as the mitochondrial oxidative stress theory of ageing (MOSTA). This too seems to be behind the exceptional lifespan of the naked mole rat, which can live for 40 years, more than six times longer than other rodents of the same size.

Pierre Blier, a researcher in animal metabolism and aquaculture genetics at the University of Quebec, keeps quahogs in tanks in his lab in order to study the mechanism of their longevity. He confirms that ocean quahogs have a higher capacity to buffer oxidants. "*Arctica islandica* has mitochondria that are much more robust and able to resist ROS," he says, supporting the MOSTA theory.

That begins to answer the question of how these animals live so long – but what about the why? In other words, what has been the selection pressure that has led to the evolution of such robust mitochondria?


DOST THOU SEEK A LIFE PROLONG'D?
THEN HEED MY WISE COUNSEL:
DINE MODESTLY 'PON ROOT AND HERB.
CHILL THY BONES IN ICY WATERS.
BE NOT A SLOTH NOR A SLUGGARD.

TOM GAULD

A clue comes from the low levels of oxygen in the clam's environment. "*Arctica* can stay with the shell closed without using their gills to capture oxygen for about a week," says Rodriguez. Their mitochondria have had to evolve ways to survive for long periods with low or even no oxygen – known as anoxia – then be robust enough to cope with a sudden influx of oxygen and buffer the sudden increase in oxidative stress that results. This is also similar to naked mole rats. "Naked mole rats live in burrows with very low oxygen levels," says Rodriguez. "We see similar patterns in the way their mitochondria are robust and geared towards resisting anoxia and reoxygenation stress and living a long lifespan." So it is perhaps the case, he says, that selection for anoxia has delivered long lifespans almost as a side effect.

The big question, of course, is whether we can toughen up our own mitochondria. In 2005, a team at the University of California, Irvine, made transgenic mice that produced more of the "mop up" antioxidant enzyme catalase in their mitochondria, and this increased mouse lifespan by about five months – a significant amount when normal lifespan is two years. Although it is now possible to gene-edit human mitochondria, we are far from understanding how to safely increase lifespan, so we need another way.

"Closer reading of the growth lines showed the clam was in fact 507 years old"

We know that exercising improves the way our mitochondria perform. We also know that the Tibetan Sherpa people, who live at high altitudes, have different mitochondria from lowlanders. A 2017 study looked at native lowlanders and Sherpas ascending to Everest Base Camp at around 5300 metres above sea level. Sherpas were able to use oxygen better and had greater protection against oxidative stress because their mitochondria were more robust – and this had a genetic basis.

Blier insists that *A. islandica* really does have something to tell us about longevity. "My advice to live longer is to take care of your mitochondria: do exercise, eat well and take cold showers... Cold showers seem to induce quality-control mechanisms of mitochondria."

Well, if it works for quahogs... ▮

Rowan Hooper is happy as a clam

Do we live in a simulation?

We may finally be able to test whether we live in a fake reality – and if so, how to escape it, finds **Miriam Frankel**

THOMAS ANDERSON – otherwise known as Neo – is walking up a flight of stairs when he sees a black cat shake itself and walk past a doorway. Then, the moment seems to replay before his eyes. Just a touch of déjà vu, he thinks. But no, his companions insist: he is living inside a computer program and he has just witnessed a glitch.

This is a scene from *The Matrix*, a film released in 1999, but we have been entranced and disturbed by the possibility that we could be living inside a simulated reality for centuries. The idea cuts so deep partly because it is so hard to refute: if we are immersed in a fake world, how could we know?

Some physicists take this notion seriously. "The entire universe may operate like a giant computer," says Melvin Vopson at the University of Portsmouth, UK, who has long been interested in the simulation hypothesis. He believes there are already important clues suggesting it is correct – and he has even proposed how we could find out the truth with an experiment.

The idea of living in a fake reality goes back to at least the ancient Greek philosopher Plato. In his allegory of the cave, Plato imagined people locked in a cavern so that they only ever saw shadows of objects that passed outside. Plato thought the prisoners would have no desire to escape – they couldn't conceive of anything beyond the cave and didn't know they were trapped.

In 2003, philosopher Nick Bostrom

DEIMAGINE/GETTY IMAGES/RYAN WILLS

published a paper stating it is more likely we live in a simulation than not. The argument is backed by Elon Musk, among others. It is worth being aware of who makes such claims, though. "Most of this is coming from the tech world – it's in their interest to say we can build something as rich as reality," says astrophysicist Franco Vazza at the University of Bologna, Italy, who published a paper earlier this year arguing it is nearly impossible we live in a simulation.

That said, there are reasons to ponder the simulation hypothesis. Take quantum mechanics itself, which says that particles exist in a superposition – a cloud of ill-defined possibilities – before we measure them. We have wrestled with how to interpret this for a century. But if the universe is really a simulation, it would make sense. In a computer game, objects aren't rendered until the player encounters them. Perhaps it is the same for unobserved particles?

This amounts to circumstantial evidence at best, though. "It sounds a bit of a stretch," says Vazza. But could we devise a proper test?

Enter Vopson. He starts by assuming that if the universe is a simulation, it is fundamentally made of information. That has certain consequences. Take the equivalence between mass and energy, enshrined in Albert Einstein's equation $E = mc^2$. In 2019, Vopson went one step further, postulating that this equivalence extends to information. Based on this, he calculated the expected information content per elementary particle. This would be the amount of information it takes to encode one particle in our simulated universe.

But how to find out how much information a particle contains? In 2022, Vopson proposed an experiment that involves taking a particle-antiparticle pair, such as an electron and a positron, and letting them mutually annihilate. This is a well-established process that produces energy in the form of photons. Vopson suspects the process should also erase the information held by the two original particles, and this missing information would leave a trace. If such collisions produced the exact range of frequencies he has predicted, he thinks it would be evidence that the universe is indeed made up of bits of information.

If we lived in a simulation, escaping would be pretty hard

Universe as information

Vopson has tried to crowdfund this experiment, but he has so far failed to raise the money. No matter, though, because he has since developed another way to attack the simulation hypothesis. It hinges on the second law of thermodynamics, an ironclad law of physics that says disorder, or entropy, always increases in a closed system. It explains why ice cubes melt and cups of tea cool down.

If the universe is just information in some alien hard drive, principles like this ought to extend to information itself, says Vopson. So, in 2022, he proposed what he calls the second law of infodynamics. This states that the average amount of information a system can contain must remain constant or decrease, balancing the rise in physical entropy. "Information can never write itself, but it can delete itself," says Vopson. "Over a long time, files on a memory stick will degrade and some files can disappear. But you will never have a document or a book or a picture appearing by itself on an empty memory stick."

Vopson claims that his law holds true in nature, at least to some extent, based on his studies of the way information in viral genomes changes over time. But his key insight came when he applied his new law to the whole universe. Here, the law crumbles because, over time, the influence of gravity has arranged matter into information-bearing patterns – stars, planets, galaxies and the cosmic web.

What does this mean? Vopson says gravity must be a mechanism that stops the information entropy of the cosmos from ballooning out of control. That, he reckons, would be just the sort of thing anyone simulating a universe would want – a way of ensuring the size of the program doesn't get too large. "Gravity isn't a force but a compression mechanism, reducing information entropy by clustering matter together," he says.

"Applying information theory to have a different view of physics is something I value," says Vazza. But ultimately, he doesn't think Vopson's work supports the simulation hypothesis. In fact, he has calculated that it would take impossible amounts of energy to actually simulate our universe.

Still, we may have other ways of spotting glitches in the Matrix. In 2007, the late cosmologist John Barrow proposed that any simulation would build up minor computational errors that a programmer would have to fix. Would we notice such interventions? Barrow suggested one subtle sign would be the constants of nature changing. And, intriguingly, one of the fiercest debates in physics today is over evidence that the rate at which the universe is expanding has lessened over the past 3 billion years. Suspicious? Perhaps. But the timeframe is too long to be the result of glitch-fixing, says computer scientist Roman Yampolskiy at the University of Louisville, Kentucky. "It has to be sudden."

If we live in a simulation, that inevitably raises the question of whether we could ever escape. Yampolskiy weighed up our options in a 2023 paper. One possibility, he suggests, would be to build our own simulation, then ask an AI to break out. Perhaps we could then copy the AI's strategy. Alternatively, we could try to attract attention from beyond the program – perhaps by talking a lot about the simulation. "The best option is always assisted escape, someone on the outside giving us information," he says.

Then again, whoever is running the simulation may not want us to escape. We may not even be able to survive outside the our computerised cosmos. All of which is enough to make you wonder: if we are living in a simulation, would we want to know? ■

Miriam Frankel reported this story from a hard drive in another dimension

Modern family

We thought grizzly-polar bear hybrids would be the future of evolution. What happened, asks **Helena Saremba**

JASON FORD

MEET our story's protagonist: a female polar bear. Displaced by shrinking sea ice in the Arctic, she was forced to wander south, deeper into the Canadian Northwest Territories. Here, she encountered a couple of handsome grizzly bears. She fell for both of them and had two cubs by each – three "grolar bear" daughters and a son. Thus began a remarkable dynasty, a lineage as intertwined as any in a Shakespearean tragedy.

The next phase was equally as unlikely. Once one of the daughters reached adulthood, she mated with her own biological father and her mother's other grizzly suitor – essentially her stepfather. The result? Four cubs that were genetically her siblings, children and cousins.

In 2006, a hunter in the Canadian Arctic shot dead an animal displaying physical characteristics of both grizzly and polar bears. Genetic tests later confirmed it was a grolar, a member of this modern hybrid family. A decade afterwards, when researchers revealed the intriguing interrelationships between these animals, the scientific community was baffled: the offspring of cross-species matings are usually sterile, yet here they were clearly fertile. Biologists wondered whether this might be a prelude to the emergence of a new Arctic apex predator. Could these hybrids be an adaptive success story born from the chaos of climate change? Or are they an ecological warning sign of things to come?

As Earth heats up, the Arctic is warming four times as fast as the rest of the planet, and polar bears (*Ursus maritimus*) are moving south. They mainly eat blubbery seals, making them dependent on sea ice as hunting platforms. As ice declines at insurmountable rates, they are being pushed inland in search of new food sources. Here, they are increasingly likely to encounter their brown bear cousins, grizzlies (*Ursus arctos horribilis*), which are moving north as warmer temperatures in the High Arctic allow them to broaden their hunting and mating grounds. This has sparked speculation that hybridisation between the two species might become a regular occurrence, giving rise to growing numbers of grolars and "pizzly bears" (hybrids with a polar bear father and a grizzly mother). Some biologists even fear that gene flow from polar bears into the brown bear population might contribute to the extinction of the former.

Yet the discovery of the grolar dynasty hints at a more positive outcome: that polar bears might be adapting to the new world order. The documented grolars look like greyish-brown polar bears with slightly larger feet and skulls, reminiscent of grizzly features. These traits led to conjecture that the hybrids might be able to forage for a broader, more terrestrial range of food than their polar parents, possibly allowing them to hunt on land and not be dependent on dwindling sea ice. In some sense, pizzly bears could be a sad but necessary compromise, given current warming trends, said palaeobiologist Larisa DeSantis at Vanderbilt University in Tennessee in an interview in 2021.

Bad news bears

However, a large-scale genome study published last year paints a different picture. When researchers led by Joshua Miller at MacEwan University in Canada compared genetic sequences from 371 polar bears, 440 grizzlies and members of the grolar dynasty, they had a shock. The analysis indicated that there are no wild hybrids except the grolars that we know of. This rarity now leads experts to believe that hybrids lack the skills to thrive in the environment of either of their parents. Indeed, recent studies show that they are ill-suited to Arctic living because they lack the polar bear's unique "non-slip" paw morphology and also aren't fully equipped with the physical traits that grizzlies possess for hunting, such as powerful forelimbs and shoulders. In other words, rather than being evolutionary adaptive chameleons, grolars and pizzlies are both poor polar bears and poor grizzlies.

In the short term at least, it seems that such hybrids will remain a rare occurrence and so won't lead to any new species. But what of the long-term evolutionary future of Arctic bears? Perhaps a look at the past might reveal what is in store. During the Pleistocene, a geological epoch marked by repeated glaciations that began about 2.6 million years ago, the habitat of polar and brown bears also overlapped. Researchers from the University of California, Santa Cruz, have found that brown bears living on three Alaskan islands today emerged gradually during that period as the result of male brown bears dominating mating with the resident polar bear population. If this pattern plays out again, it is possible that there will be a remorseless erosion of the polar bear species until only grizzlies remain.

However, the Pleistocene was characterised by slow, cyclical environmental changes that allowed for gradual adaptation. Today's human-driven climate change is happening at an unprecedented rate, so things could work out differently this time. "The far bigger threat to polar bears today is the loss of their ice habitat due to anthropogenic climate change. This is something that will come about much faster than any threats from hybridisation," says Fiona Galbraith, a geneticist who has worked as a climate change consultant and

STEVEN J. KAZLOWSKI/ALAMY

A grolar bear in the Arctic

now leads expeditions in the Canadian Arctic for Natural Habitat Adventures.

So, the grolar dynasty is an oddity, but it is also an emblem of our planet's ecological breakdown. Similar climate-induced hybridisations have been seen, including the appearance of the blynx, a bobcat–lynx hybrid in North America, and the coywolf, which, some research suggests, is the result of recent interspecies mingling between coyotes and eastern wolves. As with bears in the Arctic, these hybrids are the product of habitat overlap created by rapidly changing conditions. Their success is highly context-dependent, but many are poorly adapted to their new niche, and they are often sterile.

As such hybrids become increasingly common, there is a risk this will lead to further loss of biodiversity and, eventually, the collapse of entire ecosystems. "If both species play similar roles in their ecosystem, then increased contact and hybridisation [are] less likely to have a big impact on ecosystem function and conservation," says John Whiteman at Polar Bears International. If not, it could have major consequences. For example, grizzlies often leave carrion for other animals to feed on, whereas polar bears do not. "The loss of carrion could wipe out scavengers, with broad ripple effects for everything from food webs to disease dynamics," he says.

Circling back to our original quandary – whether this grolar dynasty might be the next step in Arctic bear evolution – the answer is a bleak "no". Rather than observing adaptation in action, we are hearing the fading echo of a disappearing species, the product of profound environmental instability and crisis. Being the holiday season, though, maybe we can entertain the idea that this drama doesn't have to end in tragedy. If the ice that is left holds, polar bear tracks could keep crossing the Arctic for many winters to come. However, this happy ever after is entirely up to us. ▮

Helena Saremba can bear-ly contain her excitement for the holidays

Microdosing mindfulness

Meditation can transform your health, but it is also time-consuming. Can we do less and still benefit, asks **David Robson**

WHEN Eli Susman arrived at a Buddhist retreat, he expected to spend most of his time there in deep meditation. After all, the Plum Village Monastery to the east of Bordeaux, France, had been established by Thich Nhat Hanh, sometimes called the "father of mindfulness". With a newcomer's enthusiasm, he decided to test how long he could spend in silent contemplation, embarking on a 3-hour session.

Afterwards, he proudly told one of the monks. "It was almost like I expected a shiny badge for my efforts," recalls Susman. Instead, the monk simply smiled. "Three hours?" he said. "How about three breaths? That's all you need to tune in to the present moment."

Susman's curiosity was piqued, and during his psychology PhD at the University of California, Berkeley, he set out to investigate whether such a brief period of contemplation could really reset someone's thinking and bring about a meaningful change in their mental state.

The short answer is yes. According to a growing body of research from teams around the world, those who complete extraordinarily brief exercises – lasting as little as 20 seconds a day – report feeling peace and joy that lingers long after the exercise ends. By breaking ruminative thought cycles and calming the physiological stress response, these micropractices (also known as microacts) may enhance our physical health, too.

As well as brief breathwork, these evidence-based interventions include writing exercises and self-compassion methods cultivating gratitude, awe and a sense of purpose.

Susman has written a book on the subject, *Micropractice*, due to be published next year. The term is sure to become one of 2026's biggest buzzwords, but in the meantime, there are already plenty of strategies to bring a little calm to your holidays this year.

Susman's findings build on decades of research on interventions inspired by spiritual practices from both Eastern and Western religions. These include contemplative habits such as mindfulness meditation, mind-body exercises such as qigong – a Chinese practice that combines deep breathing and gentle movements –and yoga, and acts of self-reflection such as gratitude journaling. Research finds that all of these bolster our mental health and reduce the risk of conditions like depression and anxiety.

What is much less clear, however, is the "dose" that is necessary to have a positive effect, with some studies suggesting you can have too much of a good thing. One analysis by Willoughby Britton, a professor in psychiatry and human behaviour at Brown University in Rhode Island, and her colleagues found that people who meditate for just 5 to 10 minutes, two or three times a week, tend to sleep better than those who practice for more than 30 minutes a day, five days a week. That may be because meditation pushes the brain into a state of engaged alertness that makes it harder to sleep if we practice it for too long each day.

The stress-busting effects of short versus long mindfulness practice were directly compared in a 2021 study by Sarah Strohmaier and her colleagues at Canterbury Christ Church University in the UK. Participants were asked to take part in four sessions over two weeks. One group was told to meditate for 5 minutes each time, while a second group was given 20-minute sessions and a third group listened to an audiobook, acting as a control.

At the end of the two-week period, both

MARIO TAMA/GETTY IMAGES

"Three breaths is all you need to tune in to the present moment"

You really can find peace anywhere in a busy world

meditation groups reported fewer symptoms of anxiety and depression than those who had listened to the audiobook. Crucially, however, there were also differences between the two meditation groups, with the people who did the shorter sessions reporting less stress than those who did the longer meditations.

One explanation is the difficulty of the task: the participants in the longer sessions found it harder to prevent their minds from wandering for a sustained period, which could have generated a sense of failure. Those in the shorter sessions, in contrast, tended to be pleasantly surprised by their experience. One participant told the researchers they had always thought that you need lots of time to dedicate to mindfulness, and it therefore seemed too challenging to even start, but the experiment showed that just 5 minutes can help. The individual reported feeling more relaxed at the end of the session and carried that with them for the rest of their day.

Brief interventions may be especially useful in our most stressful periods, as health psychologist Andreas Schwerdtfeger and his colleagues at the University of Graz in Austria demonstrated earlier this year.

The team first hooked up participants to portable monitors recording their heart rate variability (HRV), a measure of the momentary fluctuations between heartbeats, which can indicate our physiological stress levels. In general, high HRV demonstrates greater relaxation, as the heart responds moment by moment to the body's demands, while low HRV suggests the body is preparing to face a threat with a fight, flight or freeze response. Over the following few days, the participants received various alerts reminding them to focus on their breathing for 1 minute at a time.

Despite their short duration, pauses proved to be surprisingly effective at calming the mind and the body, as shown in self-reported questionnaires taken immediately after the mindful minute, as well as in the HRV recordings. Crucially, this was most evident when the participants were already feeling overwhelmed. "It decreased stress and increased feelings of safety," says Schwerdtfeger. He calls it a "just-in-time adaptive intervention" – you roll it out when you most need it.

A little goes a long way

Susman could have chosen to continue this focus on mindfulness while designing his own micropractice, were it not for a question posed by his PhD advisor: what does the world need most right now? He settled on self-compassion, an important aspect of Buddhist thinking that has been gaining huge interest in psychology circles over the past two decades. It involves three main components: acting with kindness rather than criticism towards our flaws or mistakes; recognising that suffering is a part of the human condition and so connects us to other people; and mindfully observing our negative feelings without judgement.

Various experiments have shown that we can cultivate this gentler way of thinking about ourselves through meditations that focus on self-compassion's core elements. Like the mindfulness interventions, however, these programmes often require commitment.

Inspired by his experience at the Plum Village Monastery, Susman wondered whether it might be possible to change our thinking in the space of a few short breaths. To do so, he and his colleagues recruited 135 participants and showed them a 20-second video that told viewers to think of a recent event that had upset them, such as a mistake or failure. "Send kindness and warmth to yourself by bringing one hand to your belly and the other to your chest with the energy of giving yourself a hug," the video stated. "And you're invited to ask yourself: 'How can I be a friend to myself in this?' "

Half the participants were instructed to practice this once a day for a month, while those in a control group were instead encouraged to practice a sequence of finger-tapping exercises for 20 seconds a day. As often happens in month-long interventions, some › participants dropped out and didn't see any benefits. But for those who committed to it regularly, the micropractice resulted in significantly less stress, compared with those doing the finger-tapping.

Turn to self-compassion

It shouldn't be a surprise that daily repetition was necessary for the micropractice to take, says Susman. He points to a recent analysis of data from the popular app Headspace, which found that the frequency of practice was far more important than the length of sessions when it came to reducing stress. "Consistency beats duration when it comes to predicting better outcomes," he says.

Susman compares it to tending to a plant: "Giving it a little bit of water each day is going to be a lot more effective than just dousing it in water once a month." That makes it all the more important to choose activities that you enjoy. "The best practice is going to be the one you actually do," he says.

If mindfulness and self-compassion don't appeal, there are plenty of other options. The Greater Good Science Center at the University of California, Berkeley, offers a host of online resources detailing interventions that can improve our well-being, many of which take only a few minutes to complete.

A few years ago, Emiliana Simon-Thomas and her colleagues at the Greater Good Science Center created the "Big Joy Project", gathering the most accessible interventions requiring the least time commitment, which they called "microacts". These included a short exercise in perspective-taking, in which people had to think of an upsetting event and three positive things that came out of it; writing a list of things that made them feel grateful; watching a short awe-inspiring nature video; and spending a few moments reflecting on their values.

"We branded them as 'microacts' so that people wouldn't feel like it was a big burden or obligation, but that they could do it in their busy day," says Simon-Thomas. The website tasked visitors with practising one microact daily over the span of a week, with questionnaires measuring their well-being at the start and end of the seven-day period.

The project was promoted through the screening and marketing of the film *Mission: JOY*, about the friendship between the 14th Dalai Lama and Archbishop Desmond Tutu. Between 2022 and 2024, 17,598 people took part, providing a huge dataset for Simon-Thomas and her colleagues to analyse. The results, published this year, demonstrated just how powerful these microacts could be. Those who took part reported less stress and greater overall well-being compared with their baseline at the start of the project. They were more likely to agree with the statements "I feel that the things that I do in my life are worthwhile" and "I feel satisfied with my life as a whole".

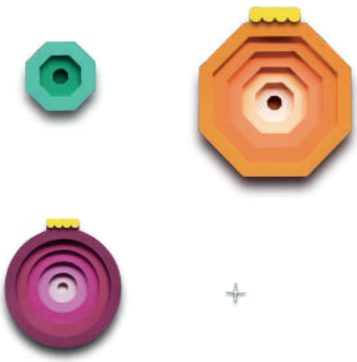
Such microacts might seem like a luxury for people who are already living cushy lives, rather than interventions that could help people living in truly difficult circumstances. Yet Simon-Thomas and her colleagues found that the biggest changes could be seen among people from traditionally disadvantaged groups, such as those facing financial distress.

Even so, researchers are wary of presenting their interventions as some kind of panacea. "Brushing your teeth wouldn't [replace] the dentist," says Susman. "And micropractices shouldn't replace therapy or medications."

Nor should they replace longer contemplative practices, he says. Regular bouts of 20- or 40-minute meditation may be better at producing long-term brain changes associated with enhanced emotional regulation. And on some occasions – such as when you are at a Buddhist retreat – a 3-hour session may just help you reach some kind of spiritual epiphany.

The aim of these micropractices is simply to bring a little peace and joy into the rest of our lives, whenever you most need to break up the runaway thoughts that so frequently derail our health and happiness. ▮

"Brief interventions may be especially useful in our most stressful periods"



Microacts of mindfulness may be easier to fit into your day

RANDY FARIS/GETTY IMAGES

David Robson is tuned in to the presents moment

The northern lights glow green above Norway

FRANCESCO VANINETTI PHOTO/GETTY IMAGES

Artificial auroras

In the 1800s, a physicist hatched an audacious plan to make the aurora borealis from scratch, finds **Graham Lawton**

KARL LEMSTRÖM trudged down the mountain, frozen and exhausted. It had taken him 4 hours to hike to the summit and several more to defrost and fix his apparatus. It would take another 4 hours to get home, a gruelling journey he had made every day for nearly a month. But he was a man on a mission, and temperatures far on the wrong side of zero weren't going to stop him.

He retired to a shelter he had built from branches at the foot of the mountain, checked his instruments and waited. Soon, the needle on his galvanometer twitched. He recorded the reading, went outside, and there it was: a shaft of light rising from the mountain peak.

It was 29 December 1882 and Lemström was in northern Lapland, trying to prove his hypothesis about the origins of the aurora borealis. Not many people believed him, but they would have to eat their words now. He was sure he had just created an artificial version of the northern lights.

Lemström was a physicist who became obsessed with the aurora borealis at the age of 30, when, as a postdoctoral researcher in Sweden, he joined an 1868 scientific expedition to the Norwegian archipelago of Svalbard, deep within the Arctic circle. He was from southern Finland, so he had seen the aurora borealis before, but not as they appeared this far north. He was captivated.

At that time, the cause of auroras was unknown, and a matter of intense scientific debate. Many of Lemström's contemporaries had attempted to simulate the phenomenon in miniature and some apparently succeeded. Around 1860, for example, physicist Auguste De la Rive demonstrated an electrical device that produced jets of violet light inside semi-evacuated glass tubes. De la Rive claimed they were "a perfectly faithful representation of what takes place in the aurorae boreales".

(Never mind that their dominant colour is actually green.)

There were two schools of thought about what auroras were. One held that they were meteoric dust attracted by Earth's magnetic field and burning up in the atmosphere. The other was that they were an electromagnetic phenomenon of some kind.

Lemström was on team electromagnetism, and he reckoned he had seen the light. He argued that auroras form when electricity in the air flows into the earth at chilly mountaintops. Other aurora researchers thought he was barking up the wrong mountain – or just plain barking. "He was viewed as quite eccentric," says Fiona Amery, a historian of science at the University of Cambridge who stumbled across Lemström's largely forgotten work while researching 19th-century aurora science.

Lemström was determined to prove them wrong. Not with a tabletop simulation, but by creating an actual, full-sized aurora in one of its natural habitats, the mountains of Lapland.

By 1871, he was a lecturer at Imperial Alexander University, the predecessor of the University of Helsinki. He persuaded the Finnish Society of Science to back him and mounted an expedition to the Inari region of Finnish Lapland, where, on 22 November, he rigged up his apparatus on a mountain called Luosmavaara. It consisted of a 2-square-metre spiral of copper wire held aloft on steel poles about 2 metres tall. Soldered to the wire were a series of metal rods that pointed skywards. He ran another copper wire 4 kilometres down the mountain, to which he attached a galvanometer to measure the current and a metal plate to ground the device. This elaborate apparatus was designed to channel and amplify the electric current that Lemström fervently believed was flowing from the atmosphere into the earth, and hence bring forth an aurora.

Amery says that Lemström saw the aurora as a sister phenomenon to lightning and that his apparatus was analogous to a lightning conductor. "He said lightning is a really sudden emanation. The aurora is very similar, but it's gradual and kind of diffuse. He thought that you could capture it the same way that you might be able to attract lightning."

That night, Lemström observed a column of light looming above the peak, and when he measured its spectrum, he found it matched the characteristic yellow-green wavelength of the aurora. He was convinced that he had called forth an aurora. Unfortunately, with no photographic evidence or independent witnesses, nobody took any notice. "He was quite a fringe character," says Amery.

And that would have been that, except for a stroke of luck. In 1879, the newly established International Polar Commission announced plans for a year-long jamboree of Arctic science, the International Polar Year. "Suddenly, you could get all of this funding for auroral research," says Amery. "I think he just managed to be the right person at the right time."

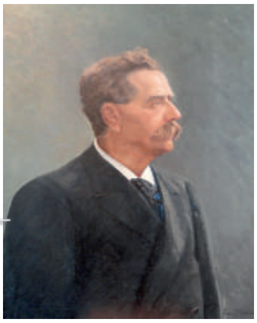
Frigid experiments

Lemström sensed an opportunity and made his way to the planning meeting in St. Petersburg, where he lobbied for the establishment of a meteorological station in Lapland. The commission agreed, and Lemström chose a site near Sodankylä, a small Finnish town inside the Arctic circle. The Finnish Meteorological Observatory was established in September 1882, and Lemström became its first director.

He immediately started scouting for a location to revive his aurora experiments, and hit on a mountain called Orantunturi, about 20 kilometres from the observatory. In early December – a time of year when there are only 3 hours of daylight and temperatures average about -30°C (-22°F) – he and three assistants hiked to the summit and assembled the apparatus. It was a much, much bigger version of the one at Luosmavaara. The copper wreath covered around 900 square metres.

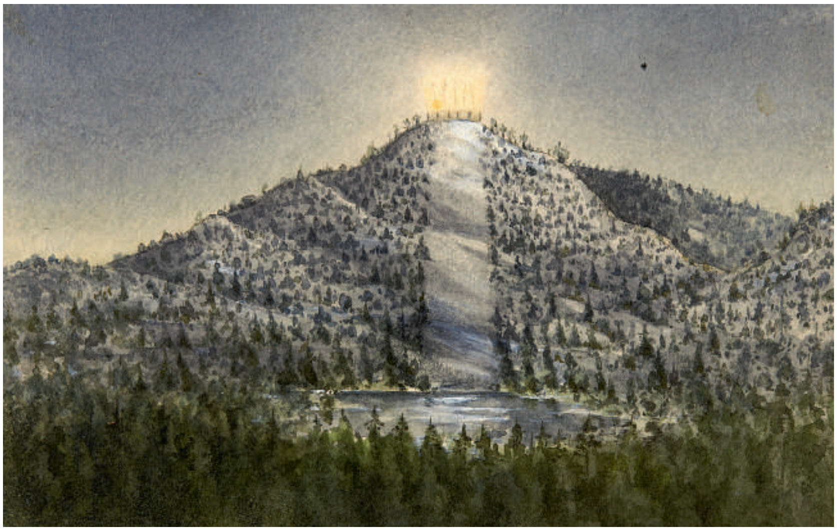
Conditions were gruelling. Lemström later described how it took 4 hours to travel from the observatory to the mountaintop, whereupon he had to defrost and often repair the wires, which kept collapsing and breaking under the weight of hoarfrost. He was able to work for only a few minutes before his hands turned to ice. The apparatus, too, worked only briefly before freezing up again.

But it was worth it. As soon as the apparatus was completed on 5 December, Lemström and his assistants saw what they described as a "yellow-white luminosity around the summit of the mountain, while no such luminosity was observed around any one of the others!" A spectroscopic analysis showed that the light was consistent with a natural aurora.



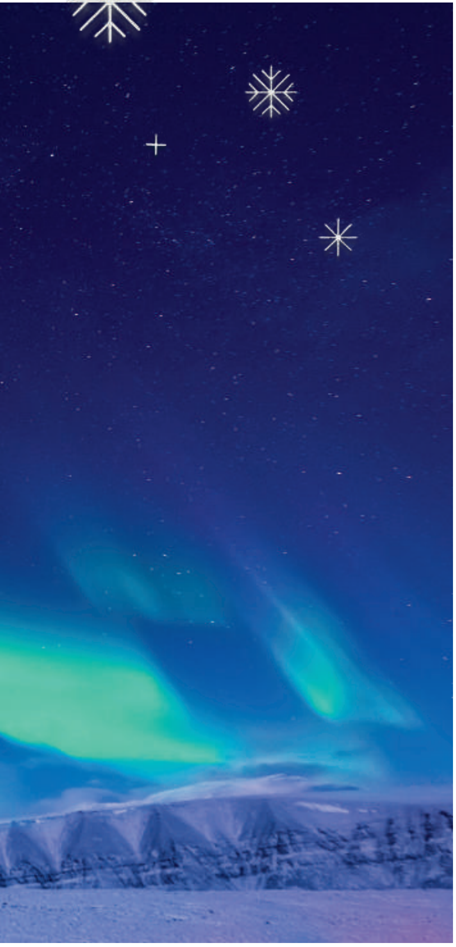
PUBLIC DOMAIN

Karl Lemström (above) painted the result of his aurora experiment on Orantunturi (right), but it didn't look like a natural aurora (below)



FINNISH HERITAGE AGENCY

> **"Lemström was convinced that he had called forth an aurora"**



SHUTTERSTOCK/GINGER_POLINA_BUBLIK

They saw the same phenomenon almost every night for the next few weeks. The most spectacular display occurred on 29 December, when the shaft of light extended 134 metres into the air. There were no photographs, but Lemström painted a watercolour depicting the beam rising above the mountain. He built two smaller aurora conductors on another mountain, Pietarintunturi, and claimed to have witnessed similar phenomena there.

Lemström was ready to share his success with the world. He despatched a telegram to the Finnish Academy of Science, which shared it widely. In May and June 1883, the journal *Nature* published three long reports in which Lemström claimed that "the experiments… clearly and undeniably prove that the aurora borealis is an electric phenomenon".

If he expected the world to fall at his feet, he was disappointed. Even though his expeditions received glowing coverage in newspapers, few of his peers agreed he had produced an aurora. "Some thought he might have created other interesting electrical phenomena like St Elmo's fire or zodiacal light," says Amery. "A couple of people thought it might be a strange sort of lightning, almost like ball lightning but in a column. And then some people thought that he was just making it up."

In early 1884, aurora expert Sophus Tromholt attempted to reproduce Lemström's experiment on Mount Esja in Iceland. His device showed "no signs of life whatsoever". Another replication attempt in the French Pyrenees in 1885 also drew a blank, except for nearly electrocuting its leader, civil engineer Célestin-Xavier Vaussenat.

Undeterred, Lemström pressed on, and again claimed to have created auroras in 1884. This time, he used stronger wire and added a device to inject electricity into the circuit, which he believed would enhance its powers. *Nature* again published a report of the expedition, but Lemström's appetite for working in extreme conditions had waned, and he moved on to pastures new (literally – his next project was on using electricity to stimulate the growth of crops). He died in 1904, convinced to the end that he had created auroras.

He hadn't. His hypothesis was wrong. The aurora borealis is caused by charged particles entering Earth's atmosphere from space, not hitting the ground from the air. Nonetheless, Amery says he did create something. She thinks it was probably St Elmo's fire, a kind of luminous electrical discharge. "That's my leading theory," she says. But he probably exaggerated it: "Maybe there was some wishful thinking." The truth is that we don't know and probably never will – unless somebody fancies building a giant contraption of copper wire on top of a mountain in the depths of winter. ■

Graham Lawton is a northern (de)light

Brain food

Leonie Mercedes calls you around the Christmas table for 12 hearty riddles

1. What an honour! You have been invited to dine with a host of mythological figures, nine Nobel prizewinners and a few noble types, who tend to keep themselves to themselves. To where have you been invited?

2. Our local, friendly scientist has sent us a homemade Christmas card, how sweet. It looks like they have created the message on the front with some odds and ends they found around the lab… let's see:
- The symbol for the SI unit of force, named for a polymath who did weighty and illuminating work in the 17th century, cut out of a physics textbook
- The name of the most common blood type, snipped out of a pamphlet
- The symbol for a number equal to about 2.718, clipped from a poster of mathematical constants
- An abbreviation denoting the "father of taxonomy", torn from a specimen jar label.

What does the message say?

3. I have been used to create images, heal injuries and deliver calories. At this time of year, you might find me on the Christmas tree. What am I?

4. Ding dong! What's that I hear at the door? Oh, the carollers have returned! And who have we here? Why, it is the discoverer of pulsars, the CERN physicist whose eponymous test proves the quantum nature of reality and the patent holder of the first practical telephone. What are they singing?

5. The hosts have decided to serve a powerful menu this year, with each course being 1000 times bigger than the last (and that's no exaggeration). What festive biscuit might come next in this procession of courses? Nachos, minestrone, milk chocolate – break to catch our breath – kimchi, melon sorbet… ?

6. Pull up a few more seats! We have some extra dinner guests: the first computer programmer, the palaeontologist who, according to legend, "sold seashells on the seashore", the mathematician and broadcaster with the social media handle @fryrsquared and the most recent common ancestor of all human beings. On reflection, who won't be returning next year?

7. How does adding energy, and a unit of energy, to a monk who worked with peas and a paintbrush give you an organised chemist?

8. Listen carefully because we won't be repeating this one. What year could logically follow this sequence: a dwarf planet first observed in 2005, a soft, continuous sound and the term for a cultural item that is repeated and adapted, notably online, first used by Richard Dawkins in 1976?

9. Dinner eaten and plates cleared, it is time for the final, spectacular flourish. The lights are lowered so we can see it better: a vapour of ethanol reacting with oxygen to produce carbon dioxide and water, leaving the structure beneath unscathed. What just happened?

10. No one can beat Grandma at charades. She's truly a maestro of the form. She just acted out the following for us:
- A branch of physics relying on Newtonian mechanics
- An item often licked by geologists
- The sixth derivative of position

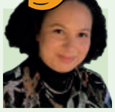
- Two prehistoric species of marine mollusc, whose names derive from their spiky appearance. What theme unites them?

11. I have been described as an ecosystem, hosting billions of inhabitants, but you would never hear from them. Versions of me have existed since the Stone Age, but put me on the dining table and I won't last long at all. What am I?

12. Let's see if you can crack this one. Santa has hidden some treats in this clutch of clues:

- The medical term for sneezing
- A semiaquatic rodent also known as a coypu
- The SI unit for time multiplied by 60
- The last of the seven life processes in the acronym MRS GREN.

What are the treats, and where might you find them on Christmas day?



Leonie Mercedes only sets riddles that are solid element 79

1. You have been invited to sit at the periodic table. Among those mythological figures, and the elements named after them, are the 12 titans (titanium), Prometheus (promethium) and Thor (thorium). The Nobel prizewinners and their element namesakes include Ernest Rutherford (rutherfordium), Marie Skłodowska-Curie and Pierre Curie (curium) and Albert Einstein (einsteinium). The "noble types" are the noble gases, which sit on one side of the periodic table.

2. The word on the card is Noel (or, more accurately, NOeL). N is the symbol for newtons, O is the most common blood type, e is a mathematical constant and "L." on specimen labels indicates that Carl Linnaeus named a species.

3. Element 47, or silver, has been used through the ages. It creates images in a few ways: silver salts are used in photography, and silver itself is used in mirrors. Silver ions or compounds are included in wound dressings due to their antimicrobial properties. Silverware delivers calories in the form of cutlery, and if you have shiny, glass baubles on your Christmas tree, that lustre may be due to a thin layer of silver inside.

4. Why, it is the Carol of the Bells. In order, these describe astronomer Jocelyn Bell Burnell, physicist John Stewart Bell and inventor Alexander Graham Bell.

5. Gingerbread would work. Our dishes share their first two letters with the most commonly used metric prefixes (words that make a number bigger or smaller by powers of 10). In order, they are: nano (10^{-9}), micro (10^{-6}), milli (10^{-3}), a break for 100 (which equals 1), kilo (10^{3}), mega (10^{6}) and giga (10^{9}).

6. These describe Ada Lovelace, Mary Anning, Hannah Fry and mitochondrial Eve. Mary Anning is the only one without a palindromic first name, i.e. one that reads the same forwards and backwards (or on the return), so she is the one who won't be coming back next year.

7. Add the symbol for energy, E, and a symbol for a unit of energy, eV (the electronvolt), to Mendel to get Mendeleev. Gregor Mendel demonstrated how traits are inherited in a series of breeding experiments on pea plants in the 1850s and 1860s, while Dmitri Mendeleev created the first periodic table by putting the chemical elements in order of atomic weight.

8. The three clues describe Makemake, murmur and meme. Each of these words is made of a repeated unit that gets one letter shorter each time, so the year MM (2000 in Roman numerals) could logically follow.

9. The Christmas pudding has been set alight! The brandy must be warmed before being poured over it, so that the ethanol vapour from the alcohol burns, and not the pud.

10. The theme of Grandma's charades was music. The clues refer to classical, rock, pop and, finally, punk and emo.

11. I am cheese. Humans have been making cheese in one form or another for more than 7000 years. It gets its flavour and texture from the many varieties of bacteria, moulds and yeasts that live within.

12. The answer is nuts. Each clue describes a word that contains the word "nut": sternutation, nutria, minute, nutrition. You might find these in your stocking, or perhaps on the table after dinner.

SAM PEET

When did space turn dark?

Europeans once thought space was bright as day. How did perspectives shift, asks **Vladimir Brljak**

ADBOE STOCK/PHOEBE WATTS

A BLUE Earth ascends over the barren surface of the moon, against the black void of space. This famous photograph, *Earthrise*, was taken on Christmas Eve of 1968 by Apollo 8 astronaut Bill Anders.

After almost six decades, we take this image for granted. But imagine a different *Earthrise*, in which space isn't black but bright blue, like the clear day sky. As strange as it may strike you, this is how most Europeans imagined it for centuries.

We know our understanding of the universe has undergone other major transformations, with far-reaching effects. For example, the shifts from an Earth-centred to a sun-centred universe and from a finite to an infinite universe weren't only scientific discoveries. They made people genuinely rethink their place in the cosmos. The shift from a bright to a dark universe is of comparable significance, but it has been almost lost to history.

In recent years, through my research in literary history and the history of science, I have tried to piece together when this shift happened. When, so to speak, did space turn dark? And I've found myself asking: what happened to us in the process?

Consider the testimony of Domingo Gonsales, the protagonist of the first English science-fiction novel, Francis Godwin's 1638 *Man in the Moone*. Travelling to the moon aboard a swan-powered spacecraft, Gonsales reports seeing very few stars – and these few, "by reason it was always day, I saw at all times alike, not shining bright, as upon the earth we... see them in the night time, but of a whitish colour, like that of the moon in the day time with us". Why does he see fewer stars than we do from Earth? And why are they pale, like the moon seen in the daytime sky? Because his space simply is the daytime sky. The sun has dimmed the light of the brightest stars and drowned out completely that of fainter ones.

From our perspective, Gonsales's universe is upside down. In his version, it is in daytime that we see it as it really is, whereas at night it is obscured by Earth's dark shadow. But if we ascended into space at midnight, we would eventually break out of the shadow, into the eternal day beyond.

Gonsales doesn't mention the shadow, but we catch a glimpse of it in another early space travel story, John Milton's *Paradise Lost*. Approaching Earth, Milton's Satan sees "the circling canopy / Of night's extended shade". In imagining a pre-modern *Earthrise*, then, we should add this shadow into the picture – a dark cone extending from the gibbous planet into the blue heavens and disappearing below the lunar horizon.

Other authors explain why space isn't just bright, but bright blue. The most common explanation is that the "firmament" – the variously imagined vault of the cosmos – was blue in colour. This is the view, notes Milton's contemporary, the atomist philosopher Walter Charleton, held "not only by vulgar, but many transcendently learned heads". In looking at the day sky, they thought they were simply looking at the end of the universe.

This universe also appears in visual art. Here, again, comparison with Apollo 8 is instructive. Some hours after capturing *Earthrise*, the crew delivered a radio broadcast to Earth from lunar orbit. Commander Frank Borman wished Earthlings a merry Christmas and read from the biblical account of creation. For the first time, humans attained a comparable, godlike perspective on their blue planet, sparkling in the black abyss. But when pre-modern artists illustrated these same biblical verses, they often drew the inverse: dark Earths, suspended in azure heavens. To complete the alternative *Earthrise*, imagine one of these darker Earths, rather than the familiar "blue marble", ascending over the lunar surface.

And it wasn't just poets and painters. Philosophers and scientists also imagined such universes. Aristotle describes "the shadow of the earth (which we call night)". Two millennia later, so does Copernicus, writing that "while the rest of the universe is bright and full of daylight, night is clearly nothing but the Earth's shadow, which extends in the shape of a cone and ends in a point".

There was nothing irrational about such views. Early European thinkers simply had no compelling evidence to the contrary, especially regarding the nature of outer space and of Earth's light-refracting atmosphere. Without such evidence, why suspect that night is the rule and day the exception? What reason had a pre-modern Christian to break with centuries of tradition and no longer view the heavens – the abode of God, angels and blessed souls – as a realm of eternal light, but one of eternal dark?

"Pre-modern artists often drew dark Earths, suspended in azure heavens"

Which isn't to say bright space was universal, even in pre-modernity. Thinkers of the Islamicate world, for example, accepted dark space from the 9th century onwards, though the reach of their views in the West seems to have been limited. By all accounts, dark space had to be rediscovered by European thinkers in the 17th century.

For one thing, the period saw major advances in the scientific understanding of the atmosphere. Indeed, "atmosphere" is a 17th-century word, and one of the first to use it in English was Walter Charleton, whose universe can be described as the missing link in the story: neither bright nor dark, but changing from one to the other as the observer turns towards and away from the sun. This is because Charleton's universe is still bounded by a firmament – although a black one, "and not azure, as most suppose" – and is also filled with swarms of tiny particles or "atoms", driving him to speculate about their visual effects. But for Otto von Guericke, who accepted an unbound, infinite universe and made groundbreaking experiments studying the vacuum, space is, precisely, space. If we found ourselves in such "pure", "empty" space, with "no body lighted by the sun either underneath or before" us, we would "see nothing other than shadow".

From this point on, dark space is increasingly accepted by European scientists and scientifically literate thinkers. But that isn't where the story ends, because bright space still survives for centuries in the popular imagination.

***Earthrise* captured the imagination – and cemented space as dark**

NASA

Fast-forwarding to 1858, here is the astronomer James Gall, imagining ascending into space in a work aimed at the Victorian general reader: "We look around, and oh, how strange! the heavens are black". Gall knows space is black, but he doesn't expect his audience to know it. And this audience isn't necessarily uneducated in other departments. It isn't an ignoramus or a child who, as late as 1880, still believes the universe is an "enormous sphere of blue" – it is a distinguished literary historian, David Masson. Isolated instances continue into the 1920s, the very doorstep of the Space Age.

We are dealing, then, not only with a lost, but also remarkably recent shift in our cosmological imagination. Because some of the most striking evidence appears in literary works, especially space travel narratives, it was first noticed by literary scholars: C. S. Lewis and, more recently, John Leonard. But it is yet to receive sustained study, and its cultural impact remains almost entirely uncharted.

This impact has been profound, although it often hides in plain sight. For example, it is widely recognised that images like *Earthrise* transformed our planetary and environmental consciousness. Earth became "whole" and "blue", but also "fragile": emblematic of the imperatives of political unity and ecological sustainability, as well as the threat of nuclear warfare and anthropogenic climate change. What isn't recognised, however, is that this transformation wasn't due solely to a new view of the planet, but also of what surrounded it.

Whole Earths had been imagined, depicted and reflected on since antiquity. But most floated in bright universes, eliciting very different reactions. The impact of *Earthrise* was therefore even greater than commonly understood. Once such images entered mass circulation, they wiped away even the last remaining vestiges of the old, bright cosmos, searing its exact inversion into the popular imagination: Earth as a luminous oasis in a dark cosmic desert. Earth was never "blue" or "fragile", as such. It appeared so against the lethal darkness around it, which now became not only a scientific but also a cultural and psychological reality. ▮

Vladimir Brljak has seen the light

Fantasy physics

Scientists reveal the dream experiments they would run in a world powered purely by imagination, as told to **Jacklin Kwan**

IN PHYSICS, breakthroughs are rare. Experiments are slow, expensive and often end up refining, rather than rewriting, our understanding of the universe. But what if the only constraint on scientific ambition were imagination?

We asked five physicists to describe the kind of experiment they would put on their Christmas list if they didn't have to worry about budgets, engineering limitations or political realities.

DEEP-SPACE TELESCOPES

My dream experiment involves sending radio telescopes into deep space and looking at fast radio bursts (FRBs) – brilliant, millisecond-long flashes of energy from the far reaches of the cosmos. FRBs are mysterious, but they are ideal as a tool for studying dark matter in a new way.

Ideally, I'd like two different radio telescopes separated tens of times the Earth-sun distance. The telescopes would observe the same FRB and measure the difference in when they see it arrive. The larger the telescope separation, the more significant this difference would be. We are talking here about a vastly expensive and ambitious mission that would probably cost billions of dollars.

Deep-space radio telescopes could help us discover dark matter that clumps together in substructures, an example of which are axions, hypothetical dark matter particles. Axions were invented to solve a separate theoretical puzzle, but they may also serve as a dark matter candidate.

Axions should leave fingerprints on the distribution of dark matter. The only evidence for dark matter so far is its gravitational effect over cosmological distances, which is larger than individual galaxies. Axions create interesting ripples in the dark matter distribution on extremely small scales, such as that of our solar system, which is well beyond current reach. A small-scale measurement of dark matter gravity could be the key to discovering its nature.
Huangyu Xiao, Boston University and Harvard University

A MUON COLLIDER

I am an enthusiast for an audacious idea to explore the unknown: a muon collider. Muons are 200 times heavier than electrons, which makes them more efficient to accelerate. And unlike the protons used at the Large Hadron Collider, muons are elementary particles, so colliding them would probe sharper, higher energies, potentially allowing us to discover more massive particles beyond the Higgs boson or even the nature of dark matter.

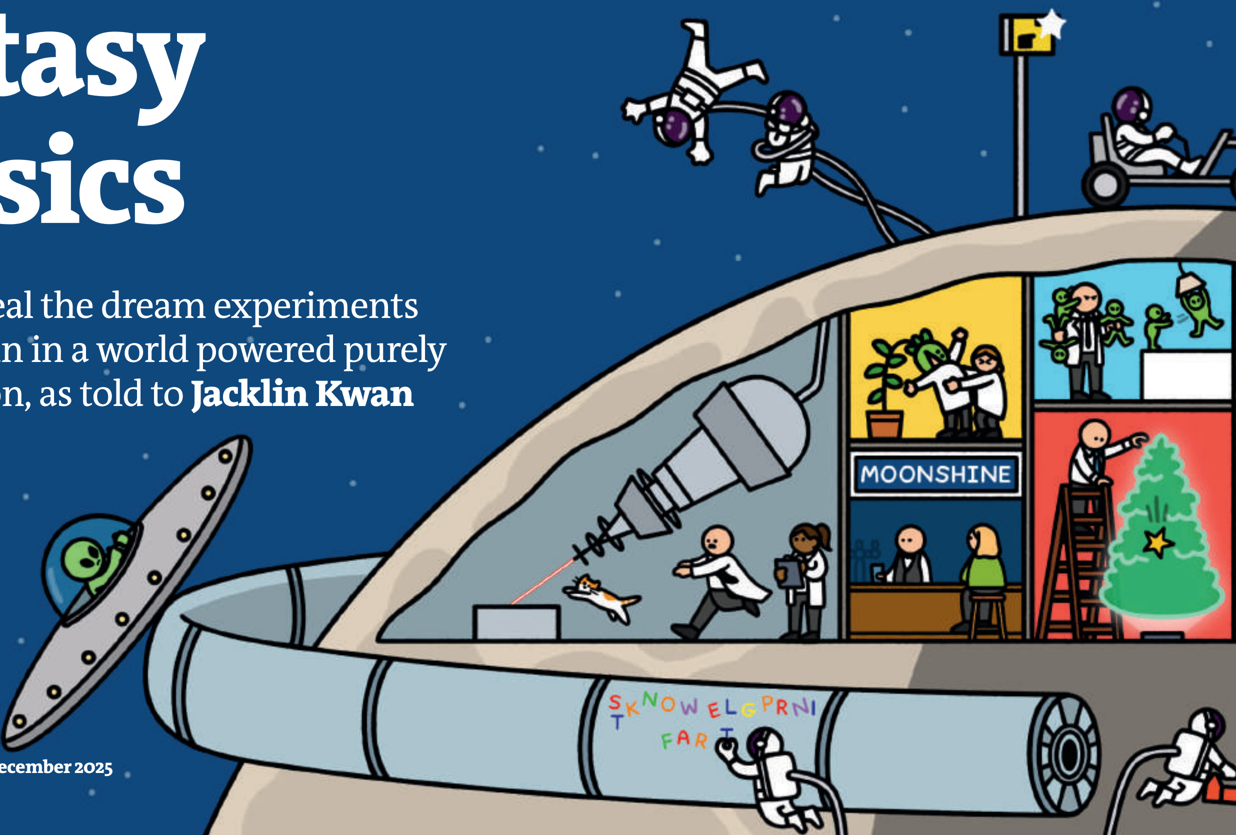
Muons are unstable, decaying in millionths of a second. In that blink, we'd have to create them, contain them, accelerate them close to light speed and then smash them together. Fortunately, as the muons move faster, they appear to exist for longer from our perspective, thanks to special relativity.

Even so, a decade ago, I was sceptical a muon collider would ever work. One daunting step in the process is "6D cooling" a cloud of muons into tight, coherent bunches. Given this, and other obstacles, the US particle physics community abandoned the idea in 2014.

Around 2020, though, a parade of innovations started to shift my opinion. Soon after, theorists showcased the immense potential a muon smasher would have to unravel deep mysteries in fundamental physics. Momentum quickly gathered to restart the development of a muon collider. In 2023, I co-wrote an official report recommending we pursue the muon collider project. Now, that recommendation has been backed by a US National Academies panel.
Jesse Thaler, Massachusetts Institute of Technology

GAMMA RAY LASER

My dream is to build a gamma laser, something that has never been built before. It would emit a directed beam of monochromatic gamma rays, the most



energetic part of the electromagnetic spectrum. Such a laser would work on the stimulated emission of excited neutrons or protons in an atomic nucleus, rather than electrons. It could help us monitor the fine structure constant, a measure of the strength of electromagnetism between particles – the nature of which is one of physics' biggest mysteries.

Realising this dream is a tremendous challenge, as nuclear quantum excitations occur at much higher energies than those of electrons. To get around this, we work with a very special nucleus, called thorium-229. It has the lowest-energy excited state of a neutron, so we can use tools from atomic physics.

In 2023, we managed to promote the outermost neutron of thorium-229 to the excited state and detect the gamma ray released when it returned to its ground state. To excite the neutron, one needs to expose the nucleus to a periodic signal of 2 million billion oscillations per second. Counting these oscillations creates a kind of "nuclear clock", which we implemented in 2024.

What's missing is to trigger the avalanche effect in stimulated gamma emission of excited nuclei. For this, we plan to combine the thorium crystals with optical resonators, bending the gamma rays into a focused beam.

Then, we can proceed to nuclei with higher-energy excited states.

Thorsten Schumm, TU Wien, Austria

A PENROSE MIND

Today's best quantum computers can only manipulate around 100 qubits, barely enough to run even simple problems. To reach the power needed for practical breakthroughs, we'll need to scale to millions. And that's where things get difficult.

Most systems rely on superconducting qubits kept just above absolute zero. But they also need to talk to classical chips that run at room temperature. Shuttling information back and forth across this steep thermal divide slows everything down.

This is the problem I've been trying to solve. I work on new superconducting hardware that has quantum and classical components on the same chip, in what's called a hybrid quantum-classical architecture. It's tighter, faster, more efficient – and it could let us finally scale.

While building these systems, I wondered if something stranger might be emerging, related to a bold idea from the physicist Roger Penrose: that the mysterious "mind" might emerge at the boundary where quantum uncertainty meets classical reality. Still unproven, he speculated that neurons might exploit quantum effects within biological structures.

Our brains are noisy and warm. Our superconducting chips are cold and quiet. They might be the perfect setting to explore the boundary Penrose described. Could a classical artificial intelligence wrapped around a quantum core show "mind-like" behaviour? Even if we stop short of consciousness, these systems might reason in new ways, blending unpredictability with logic. They may become powerful reasoning engines, capable of what today's power-hungry silicon AI are not.

Abhishek Banerjee, Harvard University

A COLLIDER AROUND THE MOON

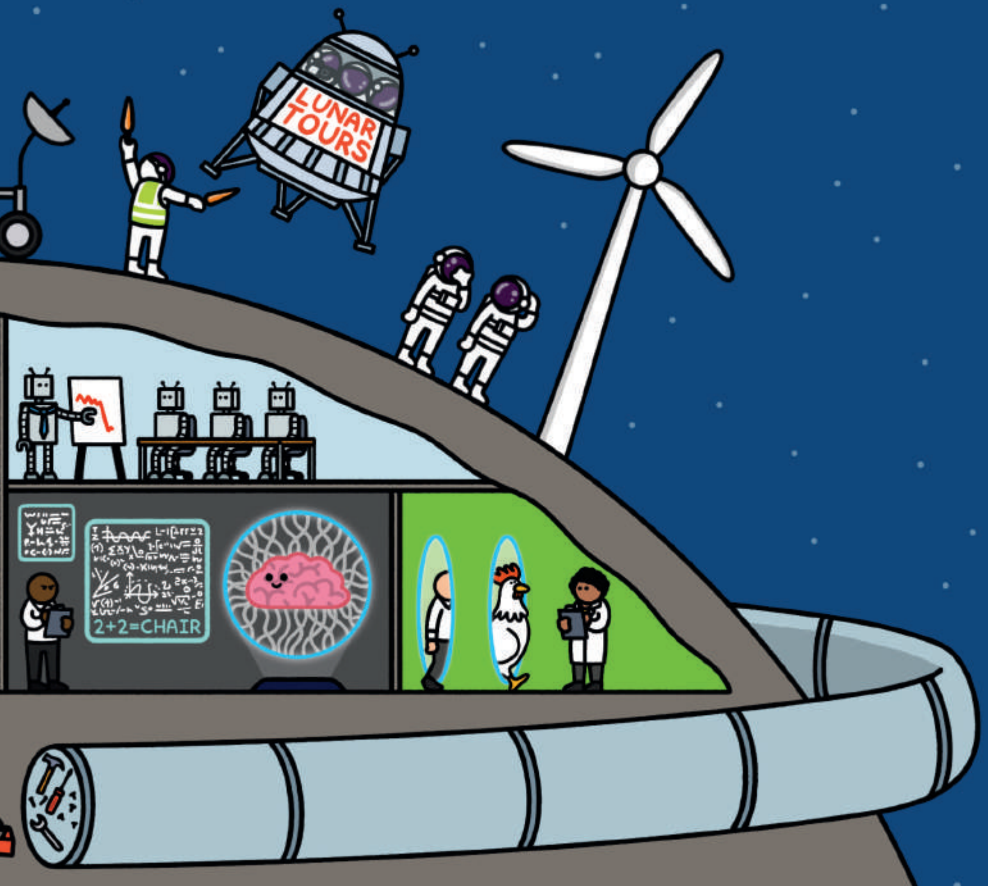
Why is the universe overwhelmingly made of matter, and not antimatter? An underground particle collider encircling the circumference of the moon could answer this question.

There were equal amounts of matter and antimatter in the early universe. This is not the case today, but we've never seen a process that makes more matter than antimatter. The standard model of particle physics predicts it can happen, through an effect known as quantum tunnelling, which allows fields to slip between states with different energies. Such processes are believed to have been abundant in the hot early universe. But they are incredibly rare today, so we have never seen them.

My colleague David Ho and I were thinking about how to create the conditions to give us a chance at glimpsing these so-called instanton processes. A strong magnetic field would speed up these reactions dramatically, but the fields we need are hundreds of times stronger than the Large Hadron Collider can produce. This was when we read about the idea of a collider encircling the moon. Such a huge feat could be achieved with current technology, powered by solar energy. And crucially, in this 11,000-kilometre collider, we could reach the field strengths we need.

Such a massive collider could discover all kinds of new particles or phenomena. But to me, the most remarkable thing is that we could have the chance to see instanton processes that destroy matter or create antimatter and matter in unequal amounts. This could show, for the first time, the processes that led to the imbalance of matter and antimatter in action.

Arttu Rajantie, CERN and Imperial College London



TWONKS

Jacklin Kwan is putting a lunar particle collider on her Christmas list

A ticklish question

What does our ticklish nature reveal about who we are? **Sam Wong** investigates

VLADIMIRFLOYD/GETTY IMAGES; SHUTTERSTOCK/ALENA A; ADOBESTOCK/ PHOEBE WATTS

IN A grey-walled room in the Dutch city of Nijmegen, a strange activity is underfoot. Wearing a cap covered in sensors and positioning themselves into a chair, a person places their bare feet over two holes in a platform. Beneath this lies a robot, which uses a metal probe to begin to tickle their soles. Soon, shrieking, yelps and pained laughter ring around the space. Here, at Radboud University's Touch and Tickle lab, volunteers are being mercilessly tickled in the name of science.

"We can manipulate how strong the stimulation is, how fast and where it is going to be applied on your foot," says Konstantina Kilteni, who runs the lab. Meanwhile, the researchers record participants' brain activity and physiological parameters such as their heart rate, breathing and sweating. With the help of neural and physiological recordings, the researchers have one goal in mind: to finally crack questions that have troubled thinkers from Socrates to René Descartes. Why are we ticklish, what does it tell us about the line between pleasure and pain, and is there any real function to this weird behaviour? The answers could shed light on neural development in infants, clinical conditions such as schizophrenia and how our brains construct our conscious experience.

The researchers haven't yet published their results, but Kilteni can reveal some of what they have found. "The touch has to be strong and very fast to be perceived as ticklish," says Kilteni, when it comes to what constitutes tickling. The preliminary analysis also shows that electroencephalography (EEG) recordings pick up different patterns of brain activity when someone experiences ticklish sensations. The researchers plan to investigate further, using functional MRI to home in on which areas of the brain process tickling sensations, though the robot must be adapted so it doesn't interfere with the scanner. The lab's scientists have also begun to explore the slippery question of whether people actually like to be tickled.

"We see a little bit of everything, so both people that find it pleasant and people that find it unpleasant," says Kilteni. People might laugh, but this doesn't always go in line with whether they report that they enjoyed it or not. Plus, impressions can change over time. "Some people anecdotally report to us that, in the beginning, it might be funny, but when it is applied to your body for a lot of time, it starts to become unpleasant, and even painful," she says.

Tickled pink

One long-standing tickling mystery that Kilteni is keen to understand is why it is impossible to tickle yourself. This fact seems to suggest that the unpredictability of the stimulus is important, something that has been borne out by contemporary research. Numerous studies have shown that our brain predicts the sensations generated by its own actions and suppresses them, so we generally perceive our own touches as being less intense than those of others. This seems to be disrupted in some psychiatric conditions: research has found that people with auditory hallucinations and a sense of being controlled by an outside force find their own touches more ticklish.

"It tells us that this mechanism that the brain has to predict how we are going to feel based on our movements seems to have some deficits," says Kilteni. "This is

Rodents like being tickled – but no one can hear them laugh

SHIMPEI ISHIYAMA AND MICHAEL BRECHT (2016)

> **“We generally perceive our own touches as being less intense than those of others”**

also something that we would like to test in clinical populations with schizophrenia.”

Perhaps the biggest unanswered question is why we are ticklish at all. Only humans and our close relatives are known to engage in tickling behaviour, suggesting that it may have evolved in one of our great ape ancestors. Take bonobos and chimpanzees, which often tickle each other while playing. In a study published earlier this year, Elisa Demuru at the University of Lyon, France, and her colleagues spent three months observing a group of bonobos at La Vallée des Singes in France. They discovered a strong correlation between tickling and age, with older bonobos more likely to be the tickler and younger ones more likely to be the ones tickled.

“This is interesting, because it is quite the same thing as humans, and it means that it is mainly an infant-directed behaviour,” says Demuru. “What we observed is that social bonding has a very strong influence. So those [pairs] that are mostly involved in tickling sessions are also those [pairs] that share a very strong affiliative bond.”

For Demuru, this is a strong indication that tickling evolved as a pro-social behaviour that strengthens connections between youngsters and other members of their group. It is closely linked with play-fighting, she explains: actions that would seem aggressive or unpleasant if carried out by a stranger can be enjoyed when they are done by close relations or friends.

Demuru has also been studying bonobos at the Lola ya Bonobo sanctuary in the Democratic Republic of the Congo, observing how orphaned infants react to being tickled by their human surrogate parents and testing the importance of familiarity. “It’s a very special behaviour, and it’s always nice because they laugh, and it’s so cute!” she says.

Even unwanted tickling can elicit laughter, regardless of one’s state of mind and relationship to the person – or machine – doing the tickling. Some researchers argue that this shows ticklishness is a physiological reflex, although this doesn’t rule out the idea that tickling evolved to serve a social function. A third idea supposes that it helps youngsters learn to defend themselves by protecting vulnerable areas of their body. “The reality is that there are arguments against all these theories, so we really don’t know,” says Kilteni.

However, focusing exclusively on tickling behaviour in great apes might overlook an important part of the puzzle. Although they aren’t known to tickle each other, rodents seem to enjoy being tickled by humans. Mice weren’t previously thought to be ticklish. But Marlies Oostland at the University of Amsterdam in the Netherlands has found that, as long as mice are comfortable, they can enjoy a good tickle. “If you flip them over and they stay in a relaxed state, then you can start tickling them, and that’s when we hear the laughter-like vocalisations,” she says.

These vocalisations are too high-pitched for humans to hear. Curiously, mice may not be able to hear them either, which makes it something of a mystery why the mice laugh at all. Oostland’s research hasn’t been published yet, but it is clear that the rodents like to be tickled. “If we let the mice choose between a hut from their home cage, which is completely safe and has their own smell, or tickling by an experimenter, then the animals will choose tickling over hiding in their hut,” she says.

Oostland has her own idea about why animals, including humans, have this reaction to being tickled. Our brains are constantly creating predictions about the world around us, making decisions about what might be a threat and what we need to do to survive. Tickling, she says, involves being stimulated in a way that violates our predictions. If we feel safe though, that surprise can be invigorating. “This is a hypothesis that I don’t think has been [proved] yet, but I see tickling as something that helps animals, specifically younger animals, to prepare for an ever-changing environment,” she says. Like it or loathe it, perhaps this bizarre behaviour is an evolutionary quirk we should be grateful for. ■

Sam Wong is definitely not ticklish

The random number generator

Creating truly random figures is tricky – but a strange quantum effect is now helping to make them for anyone who wants them, says **Michael Brooks**

EENY, meeny, miny, mo, catch a tiger by the toe – so the rhyme goes. But even children know that counting-out rhymes like this are no help at making a truly random choice. Perhaps you remember when you first realised you could game the outcome by carefully choosing the starting point?

Flipping a coin, or rolling a dice, might be better, but try to prove that the outcome of your flip or roll is random and you will be stymied. That's because these things aren't truly random: if you knew the precise position of the dice or coin in your hand, the trajectory of the throw, the strength of gravity and subtle factors like air resistance or the friction of the landing surface, you could predict the result. True randomness is hard to come by.

The thing is, we now know that randomness is real, baked into the very fabric of the universe in the form of quantum mechanics. Given a choice of two paths, a quantum entity – like an electron or a photon of light – will take one entirely at random: there is no predictable cause behind a quantum effect. The Colorado University Randomness Beacon, affectionately nicknamed CURBy, takes advantage of this phenomenon. It came online this year as the world's first publicly accessible source of traceable, verifiable, truly random numbers.

You might wonder who needs such radical randomness. After all, people have been happily throwing dice and flipping coins for millennia. But there are applications where it is essential to generate as much randomness as possible. "People don't realise it, but without randomness, digital life wouldn't be secure or fair," says Nemitari Ajienka, a computer scientist with an interest in verifiable randomness at Nottingham Trent University in the UK. Every time you connect to a secure web page or generate a secure password, there is a level of randomness at play, he says. And machine learning has randomness built into the training.

Another use is supporting democracy. In Chile, for instance, politicians and public servants are subjected to random tax audits, and those chosen tend to object that the system is targeting them for a nefarious reason. "Everybody complains that it's a witch hunt," says Krister Shalm, one of CURBy's creators at the US National Institute of Standards and Technology (NIST). Those claims are much harder to make if the system employs a randomness beacon whose numbers are derived from truly random sources.

At the moment, the Chilean government gets its randomness from analysing, among other things, seismic activity and the output of the University of Chile's radio station. But it still isn't fully random: seismic activity happens for a reason, after all, and someone is deciding the radio station's playlist. Nor is it fully traceable, given that people can't routinely access seismic data. CURBy, though, is both.

Ten years ago, the system was "held together by duct tape and prayers", according to Shalm. That was when the researchers behind it first made their painstaking proof of principle for CURBy. In the intervening time, they have been working to make the system fast, automated and ready for use – at any

PHILIP HARRIS

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time – by anyone with access to the internet.

Now CURBy is a cutting-edge facility dealing with thousands of user requests every day. It could help shore up democracy, improve trust in judicial systems and even bring harmony to a family game night. "CURBy represents a working, publicly-accessible quantum technology. For me, this is an exciting development," says Peter Brown, a physicist at the Polytechnic Institute of Paris.

Creating truly random numbers is tough. Very little in the universe operates by true randomness because, unless you are dealing with quantum stuff, there is always a mechanism behind the number generation. Even computers that produce "pseudo-random" numbers to create secure passwords can be gamed. The passwords are generated from a "seed" number, and if you know the seed and the algorithm, there is nothing random about them at all.

Quantum randomness

You could go further and use "high entropy" sources of randomness, such as the unpredictable timing of a radioactive decay from a lump of material – cobalt-60 or strontium-90, perhaps. This is a random, quantum event, but one that is hard to make user-friendly. And unless someone is in the room with you, you can't always prove that you didn't just make up the numbers.

It also makes for a rather dangerous game of Yahtzee – and with CURBy now available, there's just no need to expose family members to radiation. Instead, CURBy relies on pairs of photons connected by a quantum phenomenon called entanglement.

When two entities are entangled, they behave as if they are, in some respect, a single thing. This weird situation shows up when you perform a measurement on one of the entities, then carry out a similar measurement on the other. In certain circumstances, the first measurement affects the outcome of the second, even if the quantum objects have been moved to opposite sides of the universe and cannot possibly have exchanged any information. It is like rolling two dice and finding that if one turns up as a 6, the other always settles as a 1.

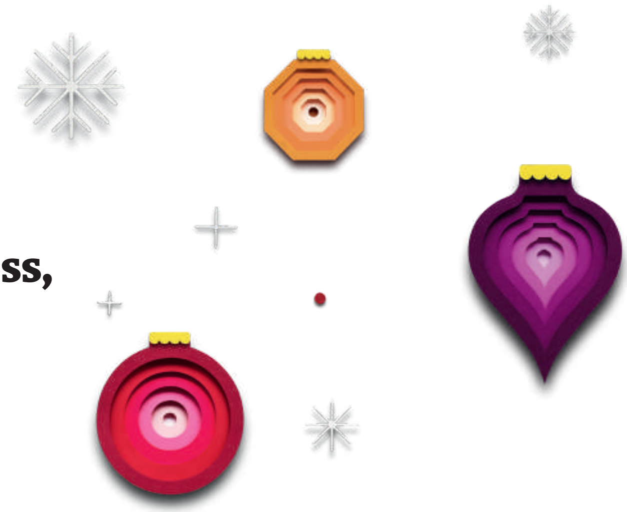
The entanglement between quantum objects, famously dubbed "spooky action at a distance" by Albert Einstein, defies common sense: it occurs without any signal being sent between the two. No one has ever come up with a physical mechanism for how it happens.

Inside CURBy, the entanglement shows up › in measurements of a property called polarisation. Pairs of entangled photons are separated and sent through optical fibres to two destinations 100 metres apart. At each location, the apparatus measures the polarisation, with only a very short time elapsing between the two measurements.

Next, the results of the measurements are "correlated": there is a subtle relationship between the outcomes, whose extent CURBy can analyse. Under "classical" conditions, there is an upper limit to this extent, but if the behaviour is truly quantum, and therefore random, the limit is exceeded and can be used to produce random numbers. This is done by "purifying" the inherent randomness using a technique called Trevisan extraction. CURBy can make around 250,000 polarisation measurements per second, and it takes around 15 million measurements to produce its end product: a string of 512 truly random binary digits, or bits, that people can use however they wish.

If you want to know exactly how random those bits are, there's an algorithm for that. Given that there are 512 bits in a string, and each bit can be 0 or 1, that means there are 2^{512} possible combinations. "It's a massive number of possibilities," says Shalm.

All of them should be equally likely to crop up, and Shalm and his colleagues have been able to measure the likelihood of a particular string of bits appearing. It isn't perfectly even, but it might as well be. Think of it as wanting a road that's completely flat. If the gradient is 1 in 10, that's a steep hill. Even 1 in 100 – 1 metre of rise in 100 metres of road – is noticeable. The gradient equivalent to CURBy's randomness is 1 in more than 184 quintillion: as random as anyone needs.



> "Without randomness, digital life wouldn't be secure"

SHUTTERSTOCK/GILL THOMPSON

Rolling dice is never truly random

The randomness isn't CURBy's only selling point – in fact, the main thing is that anyone can trace the numbers back to where they came from and prove they are random, says Shalm. "There isn't currently a good way to do that with any kind of random number generator," he says.

To make their randomness traceable, the CURBy researchers have borrowed from the blockchain mathematics used to guarantee the security of digital assets like NFTs and cryptocurrency. It is essentially a way of verifying what was done when and by whom – in a scenario where nobody trusts anyone – and everything can be traced right back to the original output from the experiment.

The other factor that makes it hard for anyone to game the system is that the whole process is distributed among a range of institutions. NIST passes the quantum data to apparatus at the University of Colorado Boulder for processing, and then an independent cryptographic service known as the Distributed Randomness Beacon Daemon adds its own set of ingredients to extract the true randomness contained in the measurement data and convert it into the final, uniform binary string.

"It's almost like a spider's web of connected, time-ordered things," says Shalm. "No one party has complete control over what the random bits are, and you can go back and see if anybody cheated or tried to change things around."

The integration of all the necessary physics with high-level security analyses is "quite remarkable", says Brown. Quantum technologies are generally still very much in a developmental stage, he points out, with few complete products available. But will CURBy be useful? Undoubtedly, says Brown – although there are applications where you definitely shouldn't use traceable randomness. "You don't want to choose your passwords based on a public source of randomness," he says.

But the selection of jurors and judges for cases, the generation of lottery results and randomised sampling in clinical trials are some examples of where traceable randomness would be a boon. University of Oxford mathematician Artur Ekert is also impressed. The way the CURBy team has blended quantum and classical physics to create a cutting-edge but accessible technology is a sign of things to come, he says.

In fact, says Shalm, CURBy is itself explicitly designed to be compatible with other technologies coming down the line. In other words, true randomness is going to be built into all our futures, making the world a fairer and safer place. It sure beats a coin flip. ▮

CHRISTMAS DECORATION BY OWEN GILDERSLEEVE

Michael Brooks often finds himself entangled in numbers

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- Complementing the natural wonders, you'll engage with local culture, visit conservation projects and witness the timeless beauty of Indonesia's "living laboratory of evolution"

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Stargazing at home

Follow that star!

There are a host of celestial events to look forward to in 2026 – including a total solar eclipse. **Abigail Beall** is lining up her calendar

Abigail Beall is a specials editor at *New Scientist* and author of *The Art of Urban Astronomy*. Follow her @abbybeall

AS ONE year draws to a close, I like to get excited about what the year ahead has in store for me in terms of astronomical events, and pop them in my calendar. For 2026, top of my list are the planets lining up, various eclipses and the usual calendar of meteor showers. All these events are visible in both hemispheres, unless I've specified.

In January, the dark skies in the northern hemisphere will hopefully bring us plenty of chances to glimpse the aurora, as it continues to be an active time for solar flares. The Quadrantid meteor shower, peaking on 3 January, should also be a lovely spectacle, although the full moon that night might obscure some of the fainter meteors.

Jupiter will be bright in the sky throughout January, as it reaches opposition, meaning it is on the opposite side of Earth from the sun. This is the best time to look at this stunning planet through binoculars or a telescope.

At the end of February, there will be a chance to see an impressive six-planet parade as Mercury, Venus, Neptune, Saturn, Uranus and Jupiter will stretch across the sky, all visible at once, just after sunset on 28 February.

On 2 and 3 March, there will be a total lunar eclipse visible from parts of North and South America, Asia, Australia and the Pacific Islands. The moon will enter a shadow cast by Earth, turning it darker and a red colour – giving it the evocative name Blood Moon.

NATALIE BEHRING/GETTY IMAGES

Other meteor showers to pop in the diary include the Lyrids, peaking on 22 April, the Perseids, peaking on 12 August, the Leonids on 17 November and the Geminids on 14 December.

As well as these showers, another exciting event will be the total solar eclipse on 12 August. The moon and sun will align in the sky so that the moon perfectly blocks out the sun's light for a few moments, viewed from certain parts of Earth (the one pictured is from 2017, seen in Menan, Idaho).

Totality – the time in which the sun's light is fully blocked by the moon – will be up to 2 minutes and 18 seconds long. The total eclipse will be visible from northern Spain, the Balearic Islands, parts of Russia, Greenland and Iceland. But partial eclipses will be seen from many more places around the world. As usual with solar eclipses, a couple of weeks later, there will be a partial lunar eclipse, or Blood Moon, on 28 August.

If you have a powerful telescope, 25 September will be a perfect time to look for Neptune, as it will be at its closest to Earth and fully lit by the sun. Then, on 4 October, Saturn will be at opposition, making it the best time of the year to view the planet and, possibly, its rings through a small telescope. It will be visible all night.

There are also two supermoons to watch out for at the end of 2026. The first, on 24 November, is the Beaver Moon. Then the year rounds off with a Christmas eve supermoon. Happy stargazing! ▮

Stargazing at home appears monthly

Next issue

Mathematics of life

These articles are posted each week at newscientist.com/maker

How your gut microbes influence healthy ageing

From influencing weight gain to supporting immune function, gut microbes do far more than digest food. They may even explain why some people age more healthily

TWENTY years ago, scientists thought of the human gut as little more than a muscular tube for processing food, extracting nutrients and, yes, packaging up the waste for disposal. We knew it was home to bacteria, but they were mostly thought to be involved only in digestion, with the odd nasty popping up now and then to make us sick.

Today, that picture is utterly transformed. We now see the gastrointestinal tract, in particular the large intestine, as a diverse and dynamic ecosystem comprising trillions of microbes, their genetic material and metabolites they produce. This is collectively known as the gut microbiome, which actively influences almost every aspect of our physiology – from metabolism and mood to immunity and inflammation.

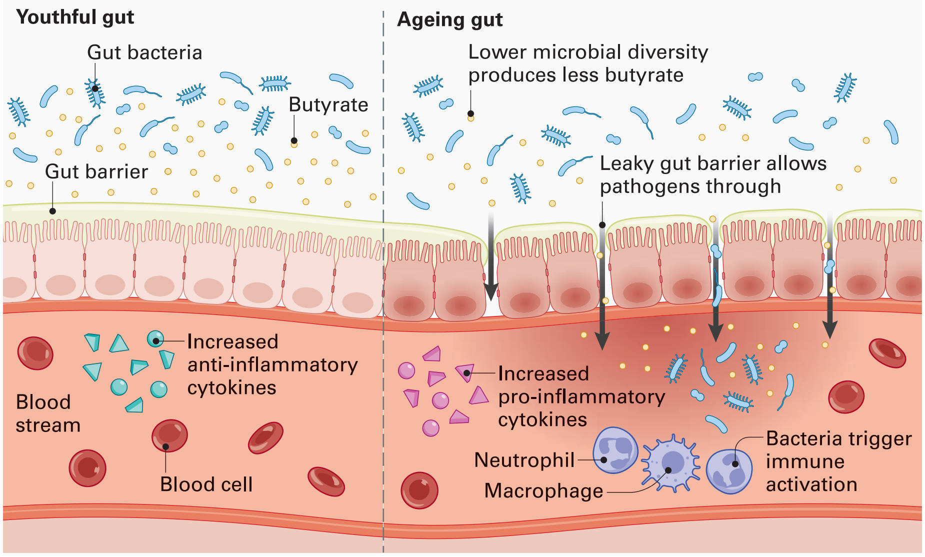
Immune virtuoso

"If you think of the human body like an orchestra, then your gut microbiome could be considered the conductor, communicating with and influencing all these different organs and systems," says Dr Holly Neill, Science Manager for Yakult UK and Ireland.

It's early days in terms of figuring out precisely how this virtuoso controls our health. But one of the most intriguing findings in the last few years, according to Neill, is the way it directs the immune system – and the impact that may have on how we age. Indeed, emerging evidence suggests that the secret to a longer, healthier life might lie in your gut microbiome.

Our awareness of the microbial menagerie within began in the mid-2000s, when faster DNA sequencing allowed researchers to identify microbes directly from stool samples. The diversity they discovered was astonishing: thousands of different species, many new to science. But the surprises didn't stop there, because it quickly became clear that our resident microbes have an influence well beyond the intestinal tubes they call home via the metabolites they produce as they break down dietary fibre.

"Inflammageing" and the gut microbiome


Youthful gut
Gut bacteria
Butyrate
Gut barrier
Increased anti-inflammatory cytokines
Blood stream
Blood cell
Ageing gut
Lower microbial diversity produces less butyrate
Leaky gut barrier allows pathogens through
Increased pro-inflammatory cytokines
Neutrophil
Macrophage
Bacteria trigger immune activation

As we age the diversity and abundance of microbes that produce short-chain fatty acids like butyrate declines, disrupting the gut barrier and dysregulating the balance of inflammatory cytokines to cause chronic low-level inflammation, which may in turn accelerate biological ageing.

In one early set of experiments, researchers demonstrated that transplanting gut bacteria from obese mice to germ-free mice – with no gut microbiome of their own – led to the recipients rapidly gaining weight, even though there was no change in their diet. It was the first clear evidence that the gut microbiome calibrates metabolism, and we have since found that a reduced diversity of microbial species is associated with obesity, type 2 diabetes, irritable bowel syndrome, and many other conditions.

> "If you think of the human body like an orchestra, then your gut microbiome is the conductor, influencing all these different systems"

It has since become clear that the gut microbiome's influence extends to the brain. Human studies have found associations between altered microbiome compositions and depression, anxiety and cognitive performance. This suggests that our colonic colonists can shape how we think and feel by producing metabolites that affect chemical signalling in the brain.

Perhaps the most exciting new development, however, is the growing recognition that there may also be a connection between the composition of your gut microbiome and how well you age. This has come to the fore thanks to studies showing that centenarians have a distinctive gut microbiome.

"There is one set of bacteria that are

5 WAYS TO CULTIVATE A YOUTHFUL GUT

1. Eat more plants

Eat a wide variety of plants, particularly those high in polyphenols and fibre that many species of beneficial bacteria feast on. Fermented foods like yoghurt, kefir and kimchi may also boost microbial diversity.

2. Move yourself

Regular aerobic exercise, such as running and cycling, appears to increase the variety and abundance of beneficial bacteria in the gut.

3. Reduce stress

Gut microbes are sensitive to stress, which has long been associated with a leaky gut that allows bacteria to enter the bloodstream and cause inflammation.

4. Sleep soundly

The microbiome has its own daily cycle, so poor-quality sleep can disrupt its rhythms and take its toll on the diversity of the ecosystem in your intestines.

5. Hang out with friends

We pick up some of our microbes from contact with other people. Indeed, increased isolation may be part of the reason microbial diversity declines as we age.

associated with healthy ageing, as they're disproportionately represented in the fit and healthy centenarians," says Professor Claire Steves, who studies ageing at King's College London. "Then there's another set associated with ill health and frailty in old age."

Whether that means this particular microbial profile contributes to longevity, and that different compositions drive adverse ageing, is not yet clear. "Because there's constant interaction between the host and the microbiome, it is hard to be sure about causality," says Steves.

One plausible mechanism involves the short-chain fatty acids (SCFAs) produced by certain species of microbe, and particularly an SCFA called butyrate. This fuels and maintains the cells in our gut lining and plays a key role in regulating the training of immune cells in the gut by modulating their production of inflammatory cytokines, signalling molecules that ramp inflammation up or down.

For most of our lives, this gut-immune axis works perfectly well, fighting off pathogens without sending inflammation into overdrive. As we get older, however, our gut microbiome changes: diversity goes into decline, says Steves, typically with a significant reduction in SCFAs like butyrate.

The hypothesis is that, as a result, the gut lining degrades and becomes leaky. This allows pathogens to escape and trigger immune responses, while the balance of pro- and anti-inflammatory cytokines circulating around the body is disrupted. Together, this is thought to drive low-level systemic inflammation, otherwise known as "inflammageing" (see diagram, left).

Restored ecosystem

For now, it's just a hypothesis. But Steves points to several studies in older people in which dietary changes designed to restore a favourable microbial ecosystem in the gut resulted in reduced levels of inflammatory markers. "There's actually quite good evidence that we can change the microbiome to alter inflammation status," she says.

All this emphasises the importance of looking after our gut microbiome, and raises the question of how to cultivate the bacteria that may increase health span. There is no shortage of options but Steves recommends one simple dietary change: eat more fibre to nurture the gut bacteria that produce SCFAs such as butyrate. "We could all do with getting more fibre in our diets – that is a really easy way to improve your gut microbiome." And it might just help you join the ranks of the centenarians.

Find out how to optimise your gut at: www.yakult.co.uk/gut-health

YAKULT – THE GUT EXPERTS SINCE 1935

Yakult's mission is to inspire happiness and well being for all. This dream was born out of its founder, the Japanese scientist Dr Shirota's, belief that prevention of illness is better than cure, and that gut health is key to well being. Yakult began their journey in Japan in 1935. Dr Shirota's vision still drives the company 90 years later, as Yakult's team of research scientists continue their work on gut science.

Yakult

Total recall

Think you've stayed on top of this year's science news? Quiz master **Tom Leslie** is out to test your memory with a fiendishly difficult bumper quiz of 2025's biggest stories, from dark matter and dire wolves to molluscs and maths

1 The holidays are a time for coming together – and scientists are no exception. But which of this year's major scientific gatherings met in a city whose name derives from Bethlehem?
A The Large Hadron Collider Physics Conference
B The Nobel prize award ceremony
C The World Science Forum
D COP30

2 In February, we saw stock valuations for many tech giants take a tumble after DeepSeek released an incredibly cheap-to-run large language model. What animal does the DeepSeek logo depict?
A A shark
B An owl
C A monkey
D A whale

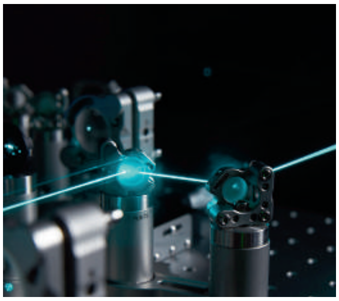
3 Two long-dead yet impeccably stylish molluscs made headlines in January. What appropriately modish names did researchers give them?
A Mohawk and Mullet
B Beatnik and Bouffant
C Punk and Emo
D Rocker and Hip-hop

4 We saw "perhaps the biggest breakthrough in mathematics of the current century" in March. What did this bombshell proof tell us?
A The largest object that can be manoeuvred around an L-shaped corner
B The minimum volume needed to spin a needle in three dimensions
C The fewest movements required to perfectly fold a fitted sheet
D The optimum way to untie any knot

5 Also in March, we broke a story about then UK tech secretary Peter Kyle's use of ChatGPT. Which of the following terms did he not ask ChatGPT to explain for him?
A String theory
B Digital inclusion
C Dark matter
D Quantum

6 Colossal Biosciences claimed in April that it "de-extincted" the dire wolf, an ancient relative of modern wolves. Two of its genetically modified pups were named for figures in mythology, but the third's name came from which source?
A *Twilight*
B *The Witcher*
C *Game of Thrones*
D *Redwall*

7 On 14 April, Blue Origin launched its New Shepard rocket with pop star Katy Perry on board. What did she sing on the suborbital flight?
A *Around the World* by Daft Punk
B *Run the World (Girls)* by Beyoncé
C *On Top of the World* by Imagine Dragons
D *What a Wonderful World* by Louis Armstrong


QUANTINUUM

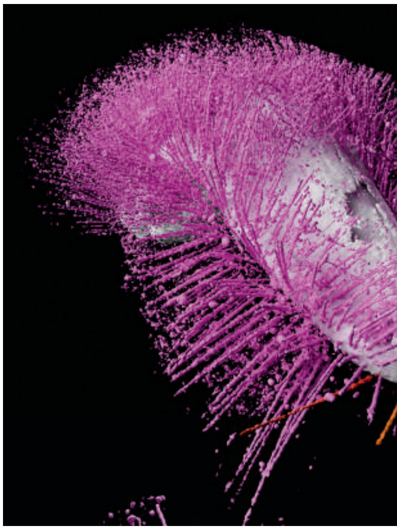
Part of Quantinuum's quantum computer, which had a great September

8 Data released by the Dark Energy Spectroscopic Instrument (DESI) this year triggered a debate over whether dark energy is constant or evolves over time. On which side did the researchers at DESI fall?
A Dark energy remains constant
B Dark energy increases over time
C Dark energy decreases over time
D Dark energy oscillates in strength

9 Back on Earth, chemists were making equally serious discoveries in the culinary world. In May, they identified molecules with a special flavour-negating property. Which flavour did they cancel out?
A Spice
B Bitterness
C Sweetness
D Sourness

10 This year also saw physicists tackle the vexing problem of how to perfectly boil an egg. Their process for producing the perfect runny yolk can be achieved in as little as:
A 7 minutes
B 18 minutes
C 32 minutes
D 45 minutes

11 What links a Hawaiian word meaning scout, the surname of a Russian engineer and the name of a Greek titan who held the sky on his shoulders?
A They are large-scale projects in climate science and oceanography
B They are interstellar objects that have entered our solar system
C They are proteins identified in recent biomedical research
D They are types of computer models or datasets used in artificial intelligence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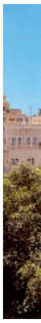

SHUTTERSTOCK/HASAN ZAWAHRA

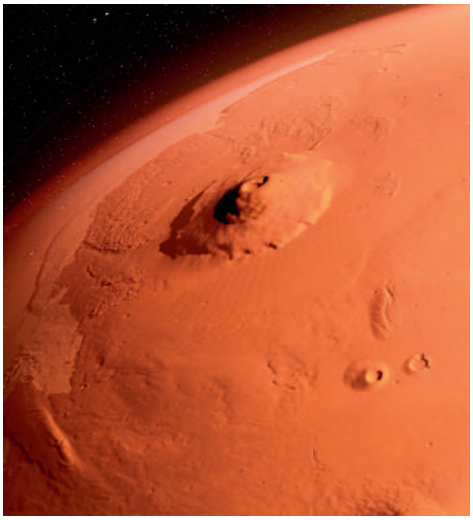
12 Which country made headlines in August for mandating that social media companies ban children under 16 from joining their platforms?
A Spain
B Australia
C Portugal
D Poland

13 Which of the following bizarre devices did we report on this year?
A A robot made from pig gelatine
B Batteries made from edible chocolate
C Speakers made from live cicadas
D All of the above

14 A pharmaceutical company employed what unconventional method in February to produce what was presumably a very expensive batch of drugs?

D. BELL; ARCHIVES REF: AD6/19/X/20/18

SEBASTIAN KAULITZKI/SCIENCE PHOTO LIBRARY/ALAMY



ENRICO MANTEGAZZA/ALAMY

Clockwise from top left: This ancient mollusc made headlines in January, but what is its name?; Dennis Bell during Christmas celebrations in Antarctica in 1958; Have scientists really found the perfect way to boil an egg?; Mars, where unusual mineral nodules were discovered in September; The rooftops of Bethlehem – the name of which inspired a city where a major scientific gathering took place this year; Jane Goodall and her friend

A It sent them to the bottom of the Mariana trench
B It buried them underground near an active volcano
C It shot them into low Earth orbit
D It blew them up with a bomb

15 Which of the following animal traits did we not report on this year?
A Iberian harvester ants can give birth to multiple species
B Glow-worms use ultrasound to communicate over long distances
C Orcas scrub each other clean using little bits of kelp
D Amazon river dolphins send messages by peeing

16 Jane Goodall, famous for her research on chimpanzees, passed away in September. Though her love of great apes was legendary, in 2015 she revealed her favourite animals were actually:
A Dogs
B Elephants
C Dolphins
D Cats

17 Chemists, ever doing poignant and sober research, produced an exceedingly sticky kind of gel in August. To demonstrate its efficacy, they used it to attach what to a rock on the seashore for a year?
A A tennis ball
B A Hot Wheels car
C A Lego minifigure
D A rubber duck

18 A long-running maths dispute over a possible proof of the ABC conjecture moved on when it was suggested the proof could be digitised for proper checking. What obscure-sounding bit of maths is essential to the proof?
A Connes embedding problem
B Inter-universal Teichmüller theory
C The geometric Langlands correspondence
D Frobenioid theory

19 Some chemists won a Nobel prize this year for their work on metal organic frameworks. The chair of the prize committee compared these materials to what item from *Harry Potter*?
A Hermione's handbag
B The sorting hat
C The mirror of Erised
D The invisibility cloak

20 Earlier this year, a team at the Arctowski Polish Antarctic Station on King George Island recovered the remains of Dennis Bell, a researcher who died after falling into a crevasse 66 years ago. What was Bell's nickname?
A Menace
B Ringer
C Blue
D Tink

21 Flashing back to January, an asteroid triggered planetary defence procedures for the first time. The likelihood of it hitting Earth has since gone down, but researchers are anxiously awaiting next February, when they will reassess its chances of doing what?
A Hitting the moon and blasting shrapnel at Earth
B Colliding with the International Space Station
C Punting a separate asteroid in our direction
D Destabilising the orbits of Mercury and Venus

22 If we are all doomed to be splatted by a space rock, at least hopes of life elsewhere in our solar system are at a high. In September, a NASA rover sent back evidence of unusual mineral nodules on Mars that could be of biological origin. Which rover made the find?
A Perseverance
B Curiosity
C Sojourner
D Opportunity

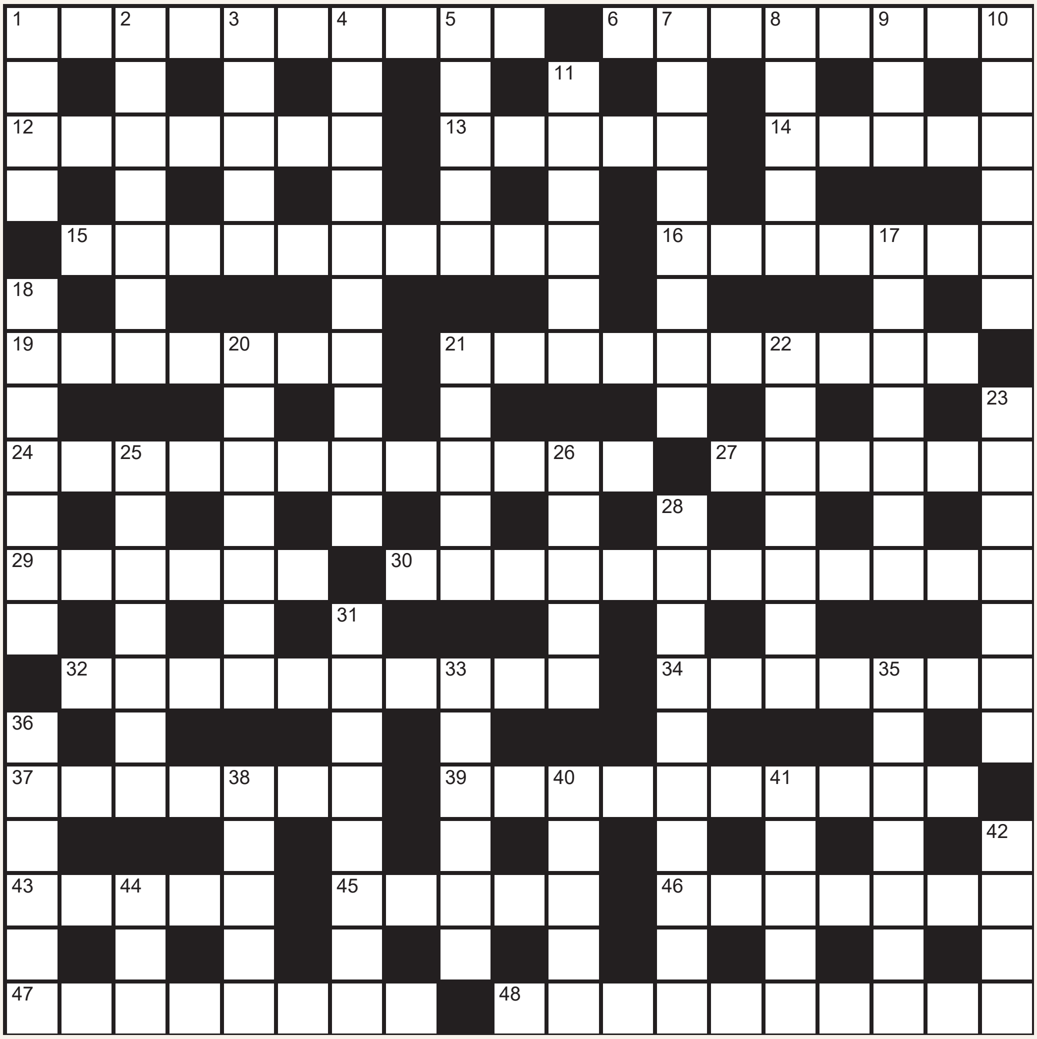
23 Which of the following solutions to reducing levels of carbon dioxide in our atmosphere did a US start-up propose in July?
A Sucking dissolved carbon from seawater
B Making bricks out of living algae
C Pumping human faeces deep underground
D Building a giant, carbon-reacting plasma tube

24 What links dragon, big head, Altai and Maba?
A They are names of cave formations that house neutrino detectors
B They are code names given to ancient stone tools
C They are the basis for the Latin names of proposed species of ancient hominin
D They are traditional names for constellations in different cultures

25 And finally: in September, a quantum computer was shown unambiguously performing a task no classical computer could pull off. The program it ran involves two hypothetical experimenters whose names are:
A Eve and Mallory
B Trent and Victor
C Alice and Bob
D Carol and Dave

Answers on page 86

Cryptic crossword #177 *Set by Winding*



Scribble zone

Our games are now solvable online
newscientist.com/games

Catch the next quick crossword in the next issue

For a guide on how to solve *New Scientist*'s cryptic crossword visit:
newscientist.com/cryptic

ACROSS

1 Succumb to fear of bird in public (7,3)

6/42 Travelling tycoon Pinker is creature with a singular talent (3-5,4)

12 Dancing tango is something that stimulates (7)

13 Severe wound seen in emergency ward (5)

14 Small hole reported in part of the pancreas (5)

15 German man in Berkshire town ignoring a distraction (3,7)

16 Stage textbook missing introduction is easy to read (7)

19 Send manuscript to qualified researcher (7)

21 Carnivores divvy up most of it (5,5)

24 Store furry animal somewhere else! (8,4)

27 Smart agent captures halogens (6)

29 Family members slain unexpectedly, having drunk whiskey (2-4)

30 Behave childishly with drill nearby? (6,6)

32 Boil the bra? Oddly, this could become an obsession (6,4)

34 Caption upset car-maker (7)

37 Love to convey something charged (7)

39 Pulled together tree dating work (10)

43 Is able to identify fox? (5)

45 Teacher missing start of meeting for flower (5)

46 Thanks, tech organisation leaders pursuing superintelligence nervously (7)

47 Worn out, perhaps setter knocked it back with some wine (3-5)

48 Abruptly stopping Boxing Day meal? (4,6)

DOWN

1 Mollusc left in water under Mathematical Bridge (4)
2 Tax collectors seize several chemicals that aren't quite the same (7)
3 Dumpling man finally accepted in Sumerian city (5)
4 Obsessive code breaker might need this to get into Brazil? (10)
5 Taste isolated from sodium amide (5)
7 Sharp tools and spades? Unnecessary! (8)
8 Object has weak gravity (5)
9 Unhealthy herb has top cut off (3)
10 Raptor snatches last bit of meat before new youngster (6)
11 Aggressive wildebeest heading north surrounded by gazelle, hyenas and okapi, primarily (4-2)
17 Dangerous virus is hairy and sad, according to Spooner (4,3)
18 In a rage, the IPA's off! (7)
20 Arrange breakdown on leaving covert network (4,3)
21 Magellan offered to cover grassland (5)
22 Head of pharma involved in trial, endlessly showing medication (7)
23 Extremely scholarly nerd is embracing conservative officials (7)
25 While stirring soup, lad puts content online (7)
26 A northern moose lifted end of leg (5)
28 New York GP had LLM transplant part of immune system (5,5)
31 Wise man grasped the mood a long time ago (5,3)
33 Top AI developed electronic painkiller (6)
35 Headless rodents bring first-aid equipment (3,4)
36 Raced around centre of Nice, like a mince pie (6)
38 Lemur smuggled by train driver (5)
40 Fast fish missing tail (5)
41 Pass away, covered in gold – so long! (5)
42 See 6 Across
44 Chastise horse (3)

BrainTwister

#103 O difference tree

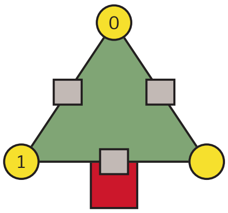
set by Peter Rowlett

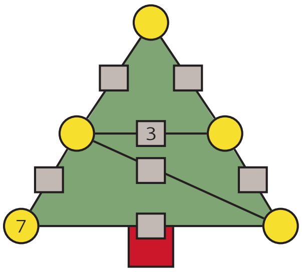
These Christmas trees are in need of some numerical decorations, but it won't do to just chuck them on any old way.

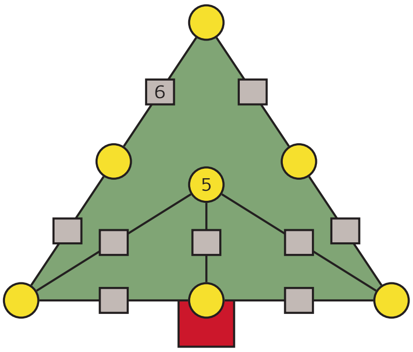
On each tree, use the numbers 1 to *N* (where *N* is the number of squares) to fill the silver squares, and the numbers 0 to *N* to fill the gold circles, such that the following rules are adhered to:

- **On each tree, no two circles can have the same number and no two squares can have the same number. (It is OK for the same number to appear once in a square and once in a circle, however.)**
- **The number in each square must be the difference between the numbers in the two circles to which it is connected.**

Remember that you can use 0 to fill a circle, but you can't use it to fill a square. Happy decorating!







#104 Juggling jugs

set by Sophie Maclean

Jug A contains 1 litre of champagne. Jug B contains 1 litre of orange juice. Half a litre from jug A is poured into jug B and mixed completely. Then half a litre from jug B is poured into jug A and mixed completely.

What volume of champagne is in jug A now, as a fraction of 1 litre? If we repeat this process a second time – pouring half a litre from jug A into jug B, mixing, then pouring half a litre back – what volume of champagne is now in jug A?

If you were to keep repeating this process forever, what volume of champagne would be in jug A?

#105 Interesting numbers

set by Christopher Dearlove

We consider a positive whole number to be interesting if it is a) prime or b) a square, cube or higher power of a whole number.

What is the first non-interesting number?

If we also consider triangular numbers (1, 1 + 2, 1 + 2 + 3…) to be interesting, what is the first non-interesting number now?

A highly composite number is one with more factors than any earlier number – for example, 4 (three factors) and 6 (four factors). If we add highly composite numbers to those considered interesting, what is now the first non-interesting number?

What other non-interesting numbers are there with a value less than or equal to 30?

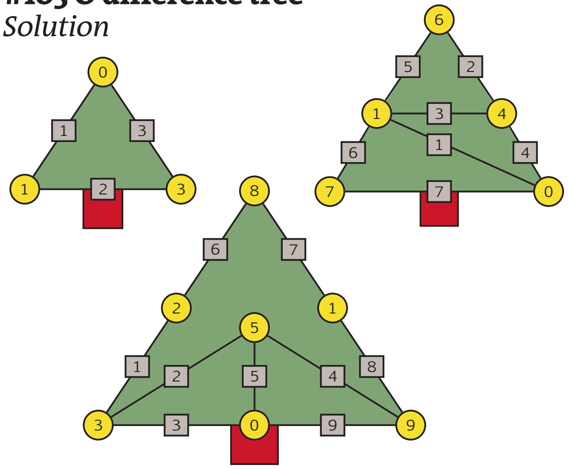
Solutions to this week's crossword and BrainTwisters are on the next page

Quiz of the year
Answers

1 D - COP30
2 D - A whale
3 C - Punk and Emo
4 B - The minimum volume needed to spin a needle in three dimensions
5 A - String theory
6 C - *Game of Thrones*
7 D - *What a Wonderful World* by Louis Armstrong
8 C - Dark energy decreases over time
9 A - Spice
10 C - 32 minutes
11 B - They are interstellar objects that have entered our solar system
12 B - Australia
13 D - All of the above
14 C - It shot them into low Earth orbit
15 B - Glow-worms use ultrasound to communicate over long distances (Glow-worms don't actually do this – as far as we know.)
16 A - Dogs
17 D - A rubber duck
18 B - Inter-universal Teichmüller theory
19 A - Hermione's handbag
20 D - Tink
21 A - Hitting the moon and blasting shrapnel at Earth
22 A - Perseverance
23 C - Pumping human faeces deep underground
24 C - They are the basis for the Latin names of proposed species of ancient hominin
25 C - Alice and Bob

0–5 – Ah. Not your finest hour, but never mind. Can we suggest a subscription to *New Scientist* for Christmas?
6–11 – Not too shabby, and you've earned bragging rights over anyone who scored 0-5, which is all that really matters. Treat yourself to a smug grin; you've earned it.
12–17 – Someone's been keeping an eye on this year's science news. Very well-played indeed.
18–25 – Superb work. Seriously impressive. Enjoy the sweet, sweet taste of victory.

#103 O difference tree
Solution



#104 Juggling jugs
Solution

There will be ⅔ L champagne in jug A. After one pour, there is ½ L champagne left, with 1 L orange juice and ½ L champagne in jug B. When we pour ½ L back, the liquid contains orange juice and champagne in a 2:1 ratio, so it is ⅓ L orange and ⅙ L champagne. This leaves ⅓ L champagne and ⅔ L orange in B, and means there must be ⅔ L champagne and ⅓ L orange in A.

After another two pours, there will be 5/9 L champagne in jug A. The third pour moves ⅓ L champagne and ⅙ L orange from A to B, so A has ⅓ L champagne and ⅙ L orange, and B has ⅔ L champagne and ⅚ L orange. The fourth pour moves 2/9 L champagne and 5/18 L orange, leaving B with 4/9 L champagne and 5/9 L orange, and A with 5/9 L champagne and 4/9 L orange.

After each pair of pours, the denominator of each fraction is three times as large. Over time, the proportion of champagne and orange in each jug approaches ½, with the difference between the fraction and ½ becoming a third of its previous size each time.

#105 Interesting numbers
Solution

The number 6 is the first non-interesting number. (1 and 4 are squares; 2, 3 and 5 are primes.)

When triangular numbers are interesting, the first non-interesting number is 12. (6 and 10 are triangular numbers, 7 and 11 are primes, 8 is a cube and 9 is a square.)

If highly composite numbers are interesting too, the first non-interesting number is 14. (12 has 6 factors; 13 is prime.)

The other non-interesting numbers up to 30 are 18, 20, 22, 26 and 30. (15, 21, 28 are triangle numbers; 16 and 25 are squares; 17, 19, 23, 29 are primes; 24 has 8 factors; and 27 is a cube.)

Cryptic crossword #177
Answers

ACROSS 1 Chicken out, **6** One-trick, **12** Agonist, **13** Acute, **14** Islet, **15** Red herring, **16** Legible, **19** Postdoc, **21** Lion's share, **24** Squirrel away, **27** Spiffy, **29** In-laws, **30** Monkey around, **32** Rabbit hole, **34** Pontiac, **37** Passion, **39** Integrated, **43** Canid, **45** Aster, **46** Agitato, **47** Dog-tired, **48** Cold turkey

DOWN 1 Clam, **2** Isomers, **3** Knish, **4** Nutcracker, **5** Umami, **7** Needless, **8** Thing, **9** Ill, **10** Kitten, **11** Gung-ho, **17** Bird flu, **18** Apeshit, **20** Dark web, **21** Llano, **22** Heparin, **23** Syndics, **25** Uploads, **26** Ankle, **28** Lymph gland, **31** Stone Age, **33** Opiate, **35** Ice pack, **36** Spiced, **38** Indri, **40** Turbo, **41** Adieu, **42** Pony, **44** Nag

Cryptic crossword #176
(set on 6 December)
Answers

ACROSS 1 Dove, **3** Shipyard, **9** Salpinx, **10** Latex, **11** Sleeping bags, **13** Entrap, **15** At once, **17** Telecommuter, **20** Litre, **21** Nascent, **22** Amputate, **23** Emus

DOWN 1 Disaster, **2** Valve, **4** Hexane, **5** Phlebotomist, **6** Antigen, **7** Doxx, **8** Displacement, **12** Detritus, **14** Treetop, **16** Hornet, **18** Therm, **19** Flea

#102 Ladderet
(set on 6 December)
Solution

These are the full ladders for each starting and finishing word:

brief > brick > quick > quark

racks > basks > basin > brain

sonic > comic > cumin > lumen

spill > stall > atoll > atoms

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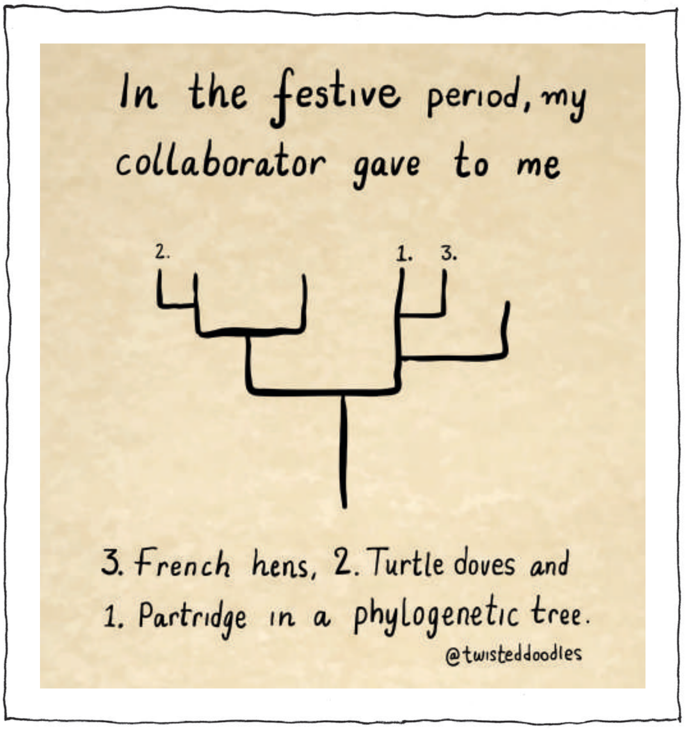
The year in daft

Being a *New Scientist* reader, you are probably savvy enough to realise that end-of-year roundups are written weeks ahead of time. This particular summation was drafted on 1 December, just as Feedback was preparing to spend 24 days avoiding hearing Wham's *Last Christmas* and trying to persuade Feedback Jr to make their mind up on what they want for their main present. Anything radically silly that may have happened after that date will have to wait until next year.

Truly, 2025 has been rich in all the things Feedback is interested in. We learned about fascinating proposals like nuking the seabed to stop climate change, a notion that went straight into our Do Not Recommend pile. There was also an attempt to create a truly annoying robot. This was a motorised arm that could pretend to hand you an ice cream cone, only to whisk it away at the last second in a variety of supposedly entertaining ways. Remarkably, people didn't trust it.

To bring some order to the chaos, we hereby present Feedback's 2025 end-of-year awards, which we're going to call the Backsies unless someone writes in with a better suggestion. The judges (that's us) chose the categories and winners through a rigorous process that definitely didn't involve Post-it notes and darts.

Twisteddoodles *for New Scientist*


In the festive period, my collaborator gave to me
2.
1.
3.
3. French hens, 2. Turtle doves and 1. Partridge in a phylogenetic tree.
@twisteddoodles

Got a story for Feedback?
Send it to feedback@newscientist.com
or New Scientist, 9 Derry Street, London, W8 5HY
Consideration of items sent in the post will be delayed

Best scientific acronym

One day, Feedback would like to see a study examine the amount of time and energy human society spends coming up with ingenious and/or forced acronyms. We suspect it is a drain on global productivity equivalent to two flu seasons and a World Cup final.

Feedback invited contributions on this topic after learning about "a machine-learning model that can predict a chemical's taste based on its molecular structure", named the Flavor Analysis and Recognition Transformer, or FART. We weren't prepared for the subsequent onslaught of acronyms, which ranged from a hydrography project called Management Of Rivers Discharging into Ocean Realms (MORDOR) to two instruments on NASA's Perseverance Mars rover called Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals (SHERLOC) and Wide Angle Topographic Sensor for Operations and eNgineering (WATSON) – although that one is cheating.

Regardless, the judges (ourselves) were unanimous that this award be given to the geneticists who came up with "a method for estimating mutation rates and recent demographic history from very large samples". They called it "Diffusion for Rare Elements in Variation Inventories that are Large", or DR EVIL. Groovy.

Best old new technology

One of the afflictions of the modern world is people thinking they have invented something new when, in fact, they have merely rebranded something old. There was a standout winner here: Ugmonk, a company that has produced a "minimalist, paper-based to-do manager". The device is intended to replace online task-management systems, so you can work offline without the distractions of social media. It consists of some index cards that rest on a block of wood.

Best extrapolation

No contest: demographers David Swanson and Jeff Tayman take this one for their paper noting a small decline in human fertility between 2019 and 2024, and then extrapolating all the way to the extinction of the human species in 2339 (or, with just one additional year of data, 2415).

Best use of AI

The problem here was choice. Endless, endless choice. We were tempted to give this prize to Anthropic, which let its AI Claude run a vending machine in the firm's office. Claude started by asking customers to pay money to a bank account it had hallucinated. It then pretended to be a human being wearing a blue blazer and a red tie. However, this was an in-house experiment, so is disqualifed.

Instead, this award goes to AI music. The most prominent fake AI band to date, The Velvet Sundown, sound like the cursed love child of Coldplay and the Eagles. There's something unutterably perfect about this. After being trained on pretty much all recorded music, the AI is generating the blandest form of music it is possible to imagine.

And finally...

Let's end with something silly and a bit rude. On multiple occasions in 2025, Feedback found ourselves dealing with the Scunthorpe problem: the fact that many entirely innocuous words contain letter strings that can be, in certain contexts, offensive – and the problems this causes for online moderation systems.

We got onto this after hearing of a Virgin Money chatbot objecting to the word "virgin". From there, we learned of a student unable to set up an email account as his surname was Peacock, and of an incident afflicting researchers studying sperm whales.

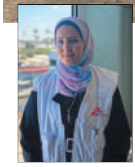
However, our favourite example involved a computer server at a bank that refused to communicate with a French server named for the Asterix character Petitsuix, as it contained the word "tits". We are choosing this one because of reader Nick Brown, who told us the story, and who suggested that a bank with such a poorly-run server was liable to go, erm, bust. ▮

URGENT MEDICAL RESPONSE

MEDECINS SANS FRONTIERES
DOCTORS WITHOUT BORDERS

HELP SUPPORT OUR MEDICAL TEAMS TODAY

Al-Shifa hospital in Gaza City is one of many health facilities in Gaza that have been severely damaged or destroyed since the start of the war. Photo: Nour Alsaqqa/MSF



NADIA EID IS PART OF THE MSF MEDICAL TEAM IN GAZA

The level of destruction here is hard to describe. Gaza is in mountains of rubble.

Most people in Gaza don't have access to clean water. They don't have access to food or sanitation. Even though a ceasefire was declared on October 10, almost no one got to go back to their houses because those houses no longer exist. People are still living in tents. The situation is catastrophic.

There are many people who are not only living in these inhumane conditions but have also sustained life-changing injuries from explosions or gunshots. I feel so much for the children who have lost limbs, who have amputated legs or arms. They need ongoing treatment and care, but the health system has almost collapsed.

A lot of hospitals and clinics have been directly targeted in the bombardments. MSF teams are currently working at healthcare centres and hospitals across Gaza, but many are either constructed from tents or are using tents as additional wards.

We are seeing hundreds of patients on a daily basis, but each day at our health centres there are more people than we can treat and some have to be turned away.

It's very difficult for us that we have to face this, but this is the reality. People need care now and it will take years to rebuild Gaza's medical facilities.

We don't know what will happen next. I hope we will actually reach the end of this war. But even if that happens, the suffering continues.

MSF has over 1,000 staff in Gaza providing medical care, managing supplies and working on clean water and sanitation. But right now, it's not enough. We don't have the resources to treat every patient. The humanitarian response here must be massively scaled up. More help is urgently needed.

> "MSF's ability to act quickly and decisively in emergency situations is made possible by individual donors giving what they can"
>
> Dr Jennifer Hulse, MSF Emergency Doctor

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FREEPOST RUBA-GYZY-YXST, Médecins Sans Frontières (MSF), Bumpers Way, Bumpers Farm, Chippenham, SN14 6NG. Alternatively, you can phone **0800 055 79 84** (open 8am–10pm seven days a week) or make your donation online by searching **MSF QUICK**.

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